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ROUTE TO SCIENCE CLASS

WHAT IS SCIENCE AND WHAT DO SCIENTISTS DO

Project "Developing Innovative Science Outreach for Vocational Education to Encourage STEM Careers and Education", ref. no. 2017-1-BG01-KA202-036327

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Introduction

HOW TO USE THIS RESOURCE

The Route to Science Class described in this document is designed so that it can be delivered by university staff and volunteer university students as an extracurricular activity for secondary VET schools.

Ideally, this class should include a pre-activity that could be a discussion inside the classroom about the methodologies used in science (Scientific Method) and/or the lives of great scientists. Watching a movie about the life of a great scientist is also a very good pre-activity that would help the participating secondary students prepare for the class.

The scientific topics covered in this activity relate to the scientific method in general and its adaptation in different scientific disciplines depending on the participating university staff/teachers/students.

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Activity concept and lesson plan

THEME OF THE CLASS

This class is designed to introduce students to the scientific method of solving problems and to provide a general introduction to science and the work of scientists.

We have strived to develop a training material that would be useful both for students in STEM-oriented schools and for students in schools where social sciences are more applicable. We are aware of controversies regarding the applicability of the scientific method in the social sciences. We are also aware that many natural scientists are convinced that social scientific research can never come even remotely close to the scientific method. However, following – to the extent possible – the basic steps and rules of the scientific method is still considered the golden rule in mainstream social science research. For this reason, we have presented the scientific method in the most generic form, allowing the materials to be directly applicable to both the exact sciences and the social sciences.

LEVEL OF DIFFICULTY / AGE OF STUDENTS

The activity targets upper secondary school students aged 16-17 (last two years of high school). The difficulty can be adjusted, if necessary, depending on the age of the students and the theme and objectives of the hands-on activity. However, the materials would not be well suited for most students below the age of 15.

REQUIRED PRIOR KNOWLEDGE

A broad intuitive understanding of science is assumed as prior knowledge in order to be able to grasp issues included in the conceptual training. However, the conceptual/theoretical training can also be adjusted to the actual prior knowledge of the students.

TIME REQUIRED FOR IMPLEMENTATION

The absolute minimum required time is 2 academic hours (one session, ca. 90 min.). However, for ensuring thorough and effective learning, a length of at least 4 academic hours is recommended, with at least 2 academic hours dedicated to conceptual and theoretical explanations. The training could be extended to several sessions including more in-depth conceptual/theoretical training and more extensive hands-on activities. The hands-on activity can include the development of a written report or a creative activity. In this case, implementation should be planned for an adequate number of sessions. The theoretical training material that we have offered includes sections that are specifically recommended for more advanced students or for more ambitious trainings.

INSTRUCTORS

There is no specific requirement about the skills of the involved university staff. The only prerequisite is that they understand, and in turn are able to explain, the scientific method using examples that are appropriate for the age and prior knowledge of high school students.

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	In this respect, good skills for science communication will be a great advantage. However, they are not a prerequisite for the success of the activity as the activity has a strong educational element.
KNOWLEDGE GAINED AND COMPETENCIES DEVELOPED - STUDENTS	Participating students will build a number of competencies, including: - Collect, interpret and analyse information in view of solving problems - Identify and use evidence to support ideas and proposed solutions - Question and critique evidence presented by others - Understand scientific information and scientific presentations - Engage with science and develop skills to practice scientific citizenship. Students will gain basic knowledge of science and the scientific method. They will be able to understand the importance of the scientific method and learn to think and act like scientists to solve particular problems. They will also understand what scientific thinking is not and what the dangers of thinking in a way that is not founded in reason and observation are.
KNOWLEDGE GAINED AND COMPETENCIES DEVELOPED – SCHOOL TEACHERS	Teachers will develop their didactical competences, in particular in explaining and teaching basic science. They will gain skills to promote scientific awareness and interest in science in an engaging way and to facilitate their students in learning to think and act like scientists rather than just memorizing facts and formulas from science textbooks.
KNOWLEDGE GAINED AND COMPETENCIES DEVELOPED - UNIVERSITY STAFF OR UNIVERSITY STUDENTS	University staff and university students involved in the implementation of the activity will improve their skills to both teach and communicate science. They will in particular gain skills to demystify and communicate core ideas of science and the scientific method to secondary students in an engaging way.
MATERIALS NEEDED FOR IMPLEMENTATION OF THE ACTIVITY	- Whiteboard for drawing diagrams and summarizing discussion. - Paper and pens for the students to take notes and document their thoughts. - Flipchart paper and color pens or markers, possibly sticky notes. - Computers, laptops or tablets (at least 1 per group) may be used for longer training sessions, if the expected output from the activity is an electronic presentation or a written report. - The activity does not require specialized equipment. It can be performed using resources that are available at every school.

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BREAKDOWN OF ACTIVITIES

This Route to Science class is divided into 3 parts:

1. Informative talk/Lecture (theoretical training): During this part, the main steps of the scientific method are presented by the university staff and key concepts are explained

2. Hands-on activity: During this part, students will be asked to:

a) identify a problem that is significant for their community

b) apply the scientific method to find a solution to the identified problem (and possibly develop a report for solving the problem): With the facilitation of the HEI staff, the participating high school students will discuss how to solve the identified problem and will offer ideas that will be recorded on the whiteboard.

3. Self-reflection on the part of students: After finishing the report, the students are invited to reflect on how they understood and applied the scientific method. They are also invited to criticize other possible solutions of the problem on the basis on their relevance to the scientific method. Questions for reflection may include (but need not be limited to):

- What are the advantages of using the scientific method?

- Are there any disadvantages associated with using the scientific method?

- How the scientific method can help political decisions and how it can promote rational critique?

USEFUL LINKS TO RESOURCES

Khan Academy, "The Scientific Method" - https://www.khanacademy.org/science/high-school-biology/hs-biology-foundations/hs-biology-and-the-scientific-method/a/the-science-of-biology

The Scientific Method, video presentation: https://www.youtube.com/watch?v=yi0hwFDQTSQ

Problem Solving: The Scientific Method, video presentation: https://www.youtube.com/watch?v=RQmqW0q85q0

SUGGESTED FURTHER READING

Details on the Scientific Method can be found in the corresponding Wikipedia lemma:

https://en.wikipedia.org/wiki/Scientific_method: in this lemma, the scientific method is described as an empirical method of knowledge acquisition involving careful observation, formulating hypotheses, via induction, based on such observations; experimental testing and measurement of deductions drawn from the hypotheses; and refinement (or elimination) of the hypotheses based on the experimental findings.

Many variations can be made on the above steps. A detailed graphical presentation (with workflow breakdown and help at each step of the

	process can be found at: https://www.sciencebuddies.org/science-fair-projects/science-fair/steps-of-the-scientific-method. A critique of the scientific method, arguing that 'scientific thinking' better fits what scientists do (a cycle of 3 phases (observe, explain, predict), can be found at: https://www.youtube.com/watch?v=j12BBcKSgEQ.
SOURCES USED TO DEVELOP THE RESOURCE	https://www.thoughtco.com/steps-of-the-scientific-method-p2-606045 https://layers-of-learning.com/a-simple-introduction-to-the-scientific-method/ Additional sources are cited within the texts below.

Background knowledge sheet

EDITORS

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INTRODUCTION TO THE TOPIC

To most people, science is the body of knowledge accumulated through discoveries. To a student, science is often a collection of isolated facts included in her textbook. However, science is also a process of discovery and a method of gaining valid knowledge about how the world works – a scientific method of gaining knowledge. Unlike the non-scientific ways of gaining knowledge, the scientific method requires a systematic approach to observation and consistent application of formal logic. Its application is what we usually call “research”.

IMPORTANCE TO DAILY LIFE/ ECONOMY /SOCIETY

The importance of the scientific method and its wide applicability stems from the fact that it tries to minimize human bias (e.g. the prejudice of people involved in scientific experiments, their personal views and/or beliefs, cultural beliefs etc.). It thus allows science to find effective solutions to a variety of societal problems, while eliminating – or at least minimizing – the impact of human error and societal factors such as culture and religion.

Bias in non-scientific “solutions” results from the fact that people usually filter or interpret information based on their own experience, and so it is highly possible that they would prefer one outcome over another on grounds that are not related to effectiveness or reliability. If knowledge is to be useful to society and if scientific results are to be applicable to a wide variety of contexts, bias should be avoided.

The scientific method provides an objective, standardized approach to designing and implementing experiments and carrying out observations. It thus improves the results drawn from these experiments and observations. By using a common standard in their work, scientists can be sure that they will interpret the facts in a way that contributes to the development of objective knowledge and minimizes personal influences.

In reality, scientists can always make smaller or more serious mistakes in the application of the scientific method. Such mistakes may include measurement errors, ignoring data that does not support their hypothesis, or using the results of previous unreliable research. To address this problem, the scientific method promotes scepticism, even for one's own scientific work. Alhazen (considered as one of the founders of the scientific method) wrote that: "The duty of the man who investigates the writings of scientists, if learning the truth is his goal, is to make himself an enemy of all that he reads, and ... attack it from every side. He should also suspect himself as he performs his critical examination of it, so that he may avoid falling into either prejudice or leniency." (see more about Alhazen from the corresponding wikipedia lemma at: https://en.wikipedia.org/wiki/Ibn_al-Haytham). Understanding the scientific method as a general process would help the student understand the basis for rational thinking and what it means to 'work as a scientist'.

DETAILED PRESENTATION ON THE TOPIC

During the process of research, scientists collect measurable empirical (observable) evidence through observation or an experiment based on a hypothesis, with the ultimate aim to support or contradict a theory. The application of the scientific method usually involves several steps.

Step 1: Making an observation about a phenomenon

Step 2: Asking the research question – determines what the research wants to know

Step 3: Inventing a tentative explanation of the observation (the answer to the research question), called a hypothesis. In the exact sciences, the hypothesis often takes the form of a causal mechanism or a mathematical relation.

A hypothesis is a testable prediction or a proposed (usually causal) relationship between phenomena that tentatively answers the research question. It can be formulated as a "if…then…" statement. A key word here is "*testable*". The hypothesis is meant to be tested and carries no assumption of truth.

Step 4: Making predictions derived from the chosen hypothesis

The scientific method always involves inference - using what we already know to learn something that we do not yet know. What we already know we use as empirical data. What we want to know is the subject of our hypotheses and theories.

The hypothesis should lead to predictions that can be test through experiment or observation. These predictions would basically specify the evidence that should be found in order to prove or falsify a hypothesis. A good hypothesis will be able to generate many predictions, as this would allow us to test it rigorously.

Good hypotheses are based on *variables*. Every research should make use of at least three types of variables:

- **Explanatory (independent) variable** – the hypothesized *cause* in a causal relationship
- **Dependent variable** – the phenomenon that we want to explain: the *outcome* in a causal relationship
- **Control variable(s)** –potential other causes of the same outcome.

Step 5: Testing the predictions by observations or experiments that can be reproduced

In order to test a hypothesis, scientists make a systematic comparison between the levels of the independent variable and the levels of the dependent variable in each different case, trying to determine whether *changes in the independent variable (the cause) are bringing a consistent change in the dependent variable (the outcome)*. If this is indeed the case, then the test would suggest that there is a causal relationship.

Step 6: Analysing the data and drawing conclusions with the goal to accept or reject the hypothesis or to modify it

Step 7: Reproduce steps 4, 5 and 6, until there are no discrepancies between observations/experiments and hypothesis. When consistency is obtained, the hypothesis becomes a theory.

A detailed knowledge resource that will guide instructors in presenting this topic is provided in Annex 1.

SCIENCE COMMUNICATION GUIDANCE TO INSTRUCTORS

- The subject of this class is characterized by a high level of abstraction and requires strong logical and analytical capabilities. It may be difficult for students to grasp and understand everything if the training session is short. Present the theoretical material in a clear, simple and unambiguous way, but without distorting it or simplifying it to a degree that makes it misleading. Focus on using examples. The examples provided in the introductory text are aimed at students with strong STEM aptitude. If you are teaching this class to students without such aptitude, you may need to pick up a less “scientific-sounding” example.

- Don’t be “just another teacher” – don’t just teach. Share with the students your passion for science. This would typically entail telling them how you got into science or why you like to do science.

- Establish a more personal connection with the students. This would typically entail telling them something about yourself or making jokes during the activity.

- When possible give examples that show how science is important and affects students’ own lives. Do this even in the theoretical part (the hands-on activity is all about that anyway).

- Try to make students curious about science – say something about the future (In the near future, our homes will look completely different….), something mysterious (Who knows what we could discover if we start to research…..”).

- You may try to provoke your students to remember and further disseminate some of what they have learned by sharing some science fact that is not widely known or is really strange, unexpected or simply “shareable on Facebook” (for example, in the part where you explain what a hypothesis is, you may want to mention some surprising hypothesis that you have heard of).

- If you use presentations, focus on including images and shapes (trying to create asymmetry on the page in order to provoke attention), rather than a long list of bullet points. Nice Creative Commons images can be downloaded from Flickr (https://www.flickr.com/). When using bullet points, always dedicate a slide to only one concept or message and never include more than 5 to 6 points. Write the text in a size that is not smaller than 28.

- If you need to use graphs, try to limit them to bubble plots (which are more easily grasped than bar graphs), bar graphs with just a few bars, pie charts or donuts, and stress the main message, using a bigger font.

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Lecture planning sheet

GOAL

Key goal: introduce students to the scientific method, focusing on the main concepts and steps and the way to organize research

SETTING

- The class can be optimally implemented with no more than 25 students. During this phase, all students remain in the same space, without forming groups or teams

- There are no requirements about the organization of the space

- The duration of this phase is min. 45 minutes

LOCATION FOR THE TALK/LECTURE

School classroom

POSSIBILE INVOLVEMENT OF UNIVERSITY STUDENTS IN THE ACTIVITY

University students can be involved in this activity as co-lecturers (they can present part of the lecture). The participation of young university students is expected to have a positive effect on the learners as it would alleviate anxiety related to the perceived difficulty of the learning matter.

TIMING & RUN-DOWN

Phase no.	**Description of phase**	Time allocated
1	**Welcome and Overview** *Presentation by the instructor*	1 min.
2	**Explaining the difference between scientific and non-scientific knowledge** *Presentation by the instructor*	5 min
3	**The scientific method: steps 1 to 3** *Presentation by the instructor*	5 min.
4	**The scientific method: steps 4 to 7** *Presentation by the instructor*	24-29 min
5	**Discussion and questions of clarification**	10-15 min

Hands-on activity/experiment planning sheet

GOAL	Key goal: allow students to apply the scientific method themselves by developing a report for solving an identified problem.
SETTING	- 10 to 25 learners (a regular class) organized in groups of 5-7. Each group tries to identify a problem and then to propose an explanation for it and possibly a solution. Alternatively, one problem could be identified for all groups (presumably by the class instructor) and in the next phase each team works on the explanation. - The space should be divided so that groups could work sufficiently far from each other as to feel comfortable and productive. The class instructor should have easy access to all of the groups. If groups are located in separate rooms, the rooms should be close to each other. - Ideally, there should be at least one facilitator assigned to each group (the task of facilitator is well-suited for university students and the school teachers that accompany the student groups). - The duration of this phase is min. 45 minutes.
LOCATION AND EQUIPMENT	Location: School classroom. Equipment: flipchart paper, spare paper and pens, as well as possibly also sticky notes, for organizing the work within the groups; flipchart necessary for the last phase. For longer training sessions, students may be encouraged to work on electronic presentations of their developed explanations/solutions or on written reports. This would necessitate that computers or tablets be provided, min. 1 per group..
POSSIBILE INVOLVEMENT OF UNIVERSITY STUDENTS IN THE ACTIVITY	University students can work in this activity as group facilitators. It is important that they have been adequately prepared before the implementation of the activity so that they know what they should do and how they should facilitate the work and interaction of groups of secondary students.
CONTENT OF THE HANDS-ON ACTIVITY	During this phase the participating students are encouraged to identify a problem that their local community is facing or is expected to face in the near future and try to think of how the scientific method could help them understand and address this problem. The problem could be related to environmental issues such as the reduction of carbon emissions, a lake that is heavily polluted, to natural disasters and how they could be prevented or even predicted, to public health within the school (how the spread of the flue could be reduced during the winter months), etc. The underlying idea is for students to address this problem by

employing the scientific method, i.e. to identify ways of understanding and possibly solving the problem that could be modelled in the form of testable hypotheses.

The students are expected to create a short report/work plan on how they would address this problem in a way that is aligned with the scientific method. This report could be oral or written, depending on the time allocated to the training. The oral report should always be in the form of a short oral presentation, preferably using the flip-chart to illustrate the developed ideas. The written report could take the form of a proposal to the local authorities, an article for the local press or a slide presentation.

See Annex II for a model hands-on activity sheet: School bullying (social sciences).

TIMING & RUN-DOWN OF THE HANDS-ON ACTIVITY

Phase no.	**Description of phase**	Time allocated
1	**Overview** *The instructor should tell the students what the objective of the activity is and how they will go about implementing it. Students should understand what they are expected to do.* *The instructor should focus on presenting the work plan and stress how the steps of the scientific method are to be followed.*	3-5 min.
2	**Description of the real-world problem to be addressed** or **Involving students in discussion to agree on a common problem** or **Providing time for each group to determine the problem they want to address** *Note: engaging students in discussion to determine a common problem can easily result in this step dragging on for a longer period of time. Instructors are advised to consider this when planning the activity.*	Up to 5 min.
3	**Group formation**	2 min.
4	**Working in groups** *University staff/students or the accompanying teachers act as facilitators. The instructor works with each group in turn.*	15 min.
5	**Presentation of results by each group** *The presentation should focus on the alternative hypotheses, the process of testing and the proposed solutions (if relevant). Students should be encouraged to present visual material (either electronic presentation or flipchart*	Up to 5 min. per group, max. 10 min. in total

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	drawing).	
6	**Reflection and discussion** *The Instructor invites the secondary students to reflect on how they understood and used the scientific method. They are also invited to critique the results of the other groups on the basis of the scientific method.*	10 min.

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Annex I: Knowledge Resource

THE SCIENTIFIC METHOD

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SCIENTIFIC KNOWLEDGE VS. NON-SCIENTIFIC KNOWLEDGE

> *"Smart people (like smart lawyers) can come up with very good explanations for mistaken points of view."*
>
> *Richard Feynman, Physicist*

In order to understand the scientific method, we first need to consider the non-scientific way of gaining knowledge. All of us – scientists and non-scientists – need knowledge. All of us need to "know" things in our daily lives. We all decide, several times a day, that something is true or false. The difference between the scientists and the non-scientists is the source of knowledge and the process through which knowledge is gained. A scientist and a non-scientist would typically need very different "proofs" and would typically go through a very different reasoning process before they accept an explanation or a statement as true or false.

Non-scientists use many sources of knowledge but most of them – such as beliefs and intuition – are subjective, unverifiable, ineffective and sometimes plain wrong. Suppose Anna strongly believes that eating one apple per day will keep her healthy. She wants to prove that this is indeed true. What would be a solid proof?

Surely, her personal *belief* is not any proof at all. Indeed, her classmate Peter thinks that apples contain too much sugar and are not so good for health. Instead, he believes he should eat broccoli to be healthy. Who is right?

Anna and Peter decide to *collect the opinions and beliefs of others*, count them, and so find if there is a *consensus* on the apple-broccoli dilemma. They go around school asking other students what they think. If they find out that more students believe apples are healthier, does this consensus prove that Anna is right? Probably not. How will Anna explain why some people nevertheless believe broccoli is healthier? How will Anna and Peter know when they have counted enough opinions to now conclude that they know the *truth*? And why would they ask only students; should they not ask also teachers, parents or even passers-by?

Anna and Peter therefore decide to look for the opinion of "*knowledge authorities*". They both sit on the Internet looking for articles from doctors, nutrition experts or public health officials. Is this a good way to find evidence for their claims? Not really. While Anna finds 100 articles praising the health benefits of apples, Peter finds other 100 articles that say similar things about broccoli. Experts, politicians and other knowledgeable individuals (or institutions) that claim to be "knowledge authorities" usually have more information and experience but they may also have a personal stake in getting their view to be accepted. For example, how can we be sure that the article that praises the health benefits of apples has not been sponsored by a big company that wants to convince people to buy more apple juice? To make things worse, even widely accepted "authoritative" views often turn out to be wrong. Let us not forget that for centuries everyone – including the world's brightest minds – claimed that the Earth was the center of the universe.

Anna and Peter agree to look for stronger evidence by making *casual observations*. Anna (who has been eating an apple a day) observes that during the last one year she was ill less often than Peter (who has been eating broccoli every day). She claims on this basis to have solved the apple-broccoli dilemma. Peter disagrees and claims that Anna has selected her observations so that they would prove her belief. Peter says Anna has counted only the times when they were so sick that

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they had to stay in bed and skip classes, but she has overlooked the number of times when they felt unwell but did not skip classes. He says she has also conveniently disregarded the fact that Peter lives in a bigger family and is thus in close contact with more people who can transmit a virus. If Peter had to fight more viruses than Anna during the year, then apples and broccoli were never on an even playing field. Anna has also forgotten that she regularly takes vitamin supplements while Peter doesn't. Could these supplements have helped apples improve her health?

Still unable to agree on who is right, Anna and Peter decide to use informal logical reasoning to support their claims. Peter refers to the Vitamin C content of apples and broccoli and reasons that broccoli is better because it has more Vitamin C, which is known to be good for health. Anna counter-reasons that apples have phytonutrients and flavonoids, which bring their own health benefits. In fact, such informal reasoning would always be prone to a great number of fallacies and inconsistencies. There may be fruits and vegetables with better vitamin and mineral content scores than apples and broccoli. There are many different vitamins and minerals that have been associated with improved health and the health benefits of their combination in apples or broccoli may be impossible to measure through "reasoning". Anna and Peter may also fail to account for many other factors such as the absorption rate of minerals and vitamins from apples and broccoli. There is no direct causality between a higher intake of a particular vitamin or mineral and general health, etc.

This – initially simple – example shows the complexity of the knowledge gaining process. Casual observation can be a good place to start when looking for clues about phenomena that interest us. Logical reasoning is also a good place to start when finding possible explanations. But neither casual observation nor logical reasoning alone are enough for gaining reliable, consistent and unbiased knowledge. How then, could humankind ever get an accurate representation of the world and accurate understanding of the phenomena around us?

SCIENCE AND THE SCIENTIFIC METHOD

> *"Truth has nothing to do with the conclusion, and everything to do with the methodology."*
>
> *Stefan Molyneux, podcaster and YouTuber*

During the process of research, scientists collect measurable empirical (observable) evidence through observation or an experiment based on a ***hypothesis***, with the ultimate aim to support or contradict a ***theory***. The application of the scientific method usually involves several steps.

Step 1

Making an observation about a phenomenon

➔ Example

The scientific world has observed that the number of children diagnosed with autism has been increasing dramatically since the 1990s. In the 1970s and 1980s, around one in 2,000 children was diagnosed with autism spectrum disorder. In contrast, 2018 data released by the Center for Disease Control and Prevention suggests that 1 in 59 children in the US have autism.

Step 2

Asking the research question – determine what you want to know

Scientists have to follow certain rules when defining their research question:

⇨ The research question should concern something that is important in the real world

- ⇨ Even if the research question relates to some important real-world phenomenon, it always needs to also make a contribution to *existing* scientific knowledge. This ensures that the efforts of the individual scientist are part of the collective scientific endeavor that helps the development of humankind. It also ensures that scientists are aware of what others have done before them
- ⇨ The research question should better avoid normative questions and questions that depend on particular cultural values[1]
- ⇨ The research question should be specific and concrete. If initially the research question is too broad, it is advisable to divide it in elements, focus it and narrow it down.

➔ Example

In our example, having observed the increasing rate of autism diagnosis among children, researchers are trying to answer an important question: What is causing this increase?

Step 3

Inventing a tentative explanation of the observation (the answer to the research question), called a *hypothesis*. In the exact sciences, the hypothesis often takes the form of a causal mechanism or a mathematical relation.

A hypothesis is a testable prediction or a proposed (usually causal) relationship between phenomena that tentatively answers the research question. It can be formulated as a "if…then…" statement. A key word here is "*testable*". The hypothesis is meant to be tested and carries no assumption of truth.

➔ Example

In our example, while scientists are still grappling with the explanation, they have already formulated several hypotheses, including:

- The incidence of autism is rising due to an environmental cause, such as exposure to pesticides or mercury
- The incidence of autism is rising due to the increasing ages of mothers and fathers, related to the fact that people nowadays delay childbearing until they are older
- The incidence of autism is not rising; it is only the incidence of diagnosis that is rising. Children nowadays are not more likely to be autistic; they are simply more likely to be diagnosed with autism than they were before. The rise in the incidence of diagnosis is related to increased awareness of the condition, increased medical surveillance and broadening of the definition of autism.

For advanced or ambitious students

> *"This isn't right. It isn't even wrong"*
>
> *Attributed to Wolfgang Pauli, physicist*

A hypothesis is only scientific if it complies with two important requirements:

- ⇨ **The hypothesis has to be empirically testable**: it should be possible to collect empirical or physical evidence or observations that will either

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[1] This requirement has been disputed in the social sciences. However, for mainstream social science research, this still remains a sensible rule.

support or contradict the predictions derived from this hypothesis

Example

In the example above, a working hypothesis is that the mother's exposure to pesticides during pregnancy is increasing the child's risk of developing autism. The researchers, focusing on a manageable number of research participants (mothers and their children), have made sure that they can collect data on the location of the mothers' homes, the location of pesticides application sites, the types of pesticides applied and the timing and frequency of their application, as well as the medical data on the children. A hypothesis for which no concrete empirical evidence could be collected would not be a good one. For example, if we hypothesize that mothers who worry a lot during pregnancy are more likely to have children with autism, we would find ourselves unable to generate objective empirical evidence to determine how much each mother worried during pregnancy and thus the research would be questionable.

- ⇨ **The hypothesis should be falsifiable**: The hypothesis should be formulated in such a way that it can in principle be rejected through empirical research or experiments. If it is not possible to reject a hypothesis, then it does not allow scientists to test it and it cannot contribute to the advancement of science. A hypothesis that is able to be wrong would be precise and narrow. Hypotheses that contain truisms, broad statements, tautological statements, normative assertions or statements derived from values and beliefs, do not have a place in science.

Example

Let us assume that our hypothesis is: “No human being can live forever”. Anyone trying to disprove our hypothesis will need to observe all human beings forever. So, falsifying this statement will take forever. In fact, proving this statement is also not possible because we can only point to *lack of evidence* that someone has ever lived forever. But, again, in order to be sure that this lack of evidence proves our statement, we have to observe all human beings forever. While it is in all probability true, this hypothesis does not belong to science. It is not a matter of investigation or research.

A falsifiable hypothesis can read for example: “Human beings die before they reach the age of 130 years”. To prove it, we can examine life expectancy statistics and show that all people for whom statistics is available died before the age of 130. As soon as someone finds a human being who is 131 years old, this hypothesis will be proven wrong. Like with the unfalsifiable statement above, we will never be able to prove this falsifiable statement with absolute certainty because we cannot have statistics for all people who have ever lived and will ever live in the future. But the hypothesis can be regarded as belonging to science and as a valid one, because *it has never been disproved even though it can be disproved.*

Step 4

Making predictions derived from the chosen hypothesis

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The scientific method always involves inference - using what we already know to learn something that we do not yet know. What we already know we use as empirical data. What we want to know is the subject of our hypotheses and theories.

The hypothesis should lead to predictions that we can test through experiment or observation. These predictions would basically specify the evidence that we need to find in order to prove or falsify a hypothesis. A good hypothesis will be able to generate many predictions, and it will be a good one because it will allow us to test it rigorously (KKV 1994: 11-19).

➔ Example

In our example, one of the alternative hypotheses is that the mother's exposure to pesticides during pregnancy is increasing the child's risk of developing autism. If the hypothesis is valid, we would expect that the children of mothers who lived near agricultural areas where pesticides were used would be more likely to be diagnosed with autism than the children of mothers that lived in environmentally clean areas or in cities. Moreover, we would expect that the closer the homes of the mothers are to the pesticide area, the higher the incidence of autism among their children will be.

For students interested the social sciences

=> Additional example

The 'democratic peace theory' hypothesizes that democratic countries rarely or never go to war with each other, but are likely to go to war with non-democratic countries. In order to prove or disprove this hypothesis, we need to collect historical data about the incidence of war. For the data to support the hypothesis, it should for example show:

- a very low rate of incidence of armed conflict between democratic countries and a relatively high rate of incidence of armed conflict between non-democratic and democratic countries
- countries have been less likely to engage in armed conflict with another democracy during the periods when they were governed as a democracy and more likely to do it during the periods when they were not democracies.

If actual historical data fits these predictions, the hypothesis would be supported. If actual historical data contradicts these predications, the hypothesis would be rejected.

Step 5

Testing the predictions by observations or experiments that can be reproduced

Step 6

Analysing the data and drawing conclusions with the goal to accept or reject the hypothesis or to modify it

➔ Variables

Good hypotheses are based on *variables*. The variable is the aspect of reality that we study. Every research should make use of at least three types of variables:

- **Explanatory (independent) variable** – the hypothesized *cause* in a causal relationship
- **Dependent variable** – the phenomenon that we want to explain: the *outcome* in a causal relationship

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- ⇨ **Control variable(s)** –potential other causes of the same outcome. We will discuss them below.

For advanced or ambitious students

Good research would consider not just the dependent, independent and control variables, but also:

- ⇨ **Intervening variable(s)** – phenomena that are an inextricable part of the causal explanation. The problem with these phenomena is that they bring additional complexity as they may be affected by other causes, too.
- ⇨ **Condition variable(s)** – phenomena that are *prior conditions* for the causal relationship to happen (van Evera, 1997: 11)

Example

Assume that we hypothesize the following: "Large national markets bring economies of scale which increase the profit of foreign investors. In this way, large market size contributes to attracting more foreign direct investment in the national economy". The independent variable here is market size. It is the cause of changing levels of foreign direct investment. The level of foreign direct investment in the country is the dependent variable. Economies of scale will be an intervening variable (they are part of the explanatory mechanism). At the same time, there are several preconditions for the causal relationship to work, e.g. stable political situation in the country, country's openness to international trade and investment, etc. If those preconditions were not met, most foreign investors would not invest in the country regardless of the size of its market.

➔ Data

Data always relates to the variables that we have chosen to study. The variable is a measurable concept constructed by the researcher, and it is called "variable" because it will take different values in different cases (van Evera, 1997: 10). In quantitative research, these values would be numeric, such as size, distance, share, degree, etc. In qualitative research, the values can be descriptive (e.g. level of development, degree of dependence, category or type). In both styles of research, however, it holds that researchers should avoid variables that are difficult to measure or observe[2].

Scientists collect data by recording the different values of the variables in a preselected number of cases. Depending on what they are studying, the cases could be individuals, cells, physical substances, countries, firms, economic sectors, geographical regions, cities, time series, events, etc. (KKV 1994, 51). The data can be collected by observation of what is happening in the real world or by conducting experiments. What is important is that the chosen cases are relevant to the phenomenon that scientists are examining and that they are sufficient in number. The number of cases is crucial for judging the validity of the conclusions because a hypothesis that holds in a small number of cases is more likely to be wrong than a hypothesis that holds in a large number of cases.

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[2] Social science research faces much more serious issues of measurability and observability of the variables than research in the natural sciences. Social science research involves studying variables that are *not directly observable* and cannot be measured directly or quantified (ideological or religious beliefs, perceptions of policymakers, consumer preferences, etc.). In such situations, it is the task of the researchers to come up with an observable or measurable indicator (a manifestation) of the phenomenon they study (e.g. ideological beliefs in the society can be determined through voting patterns, perceptions of policymakers can be determined on the basis of their public statements or interviews, etc.). Tacking this issue is an essential part of the work of the social scientist.

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➔ Using data on the dependent and the independent variables to test the hypothesis

In order to test a hypothesis, scientists make a systematic comparison between the levels of the independent variable and the levels of the dependent variable in each different case, trying to determine whether *changes in the independent variable (the cause) are bringing a consistent change in the dependent variable (the outcome)*. If this is indeed the case, then the test would suggest that there is a causal relationship.

It is important that the research or the experiment is constructed so that the values of the independent variable change across the cases. If the independent variable remains the same, it would be impossible to show that it is causing the outcome. However, if the dependent variable (the outcome) changes across cases in which the independent variable (the cause) remains the same, this means that something else is causing the outcome.

➔ Example

In our example, several studies have been carried out in which researchers used pesticide-use reports and compared autistic children with non-autistic children, noting whether their mothers lived near agricultural chemical application sites or not. The participants have been categorized into zones depending on the distance between the mother's home and the application site or depending on the types of pesticides applied (see for example, Shelton *et al.* 2014; Samson, 2007).

The units they studied were a particular number of children, some of whom were diagnosed with autism and others who were not diagnosed with autism. The dependent variable was "diagnosis of autism". The independent variable was "exposure to pesticides during prenatal development" (measured by the distance between the home of the mother to a pesticide application site and the frequency of pesticide application).

The hypothesis would be strongly supported if it turns out that within the group of autistic children, most of the mothers lived near a pesticide application site, while within the group of non-autistic children most of the mothers lived far from such a site. The stronger the association, the more substantial the impact of the independent variable would be. If within the autism group 90% of the mothers lived near a pesticide application site, then the impact of pesticides can be argued to be very strong. If within the autism group only 60% of the mothers lived near a pesticide application site, then the impact would not be that strong.

For the curious

In our example, most of the studies concluded that the children of mothers who lived near agricultural chemical application sites had higher risk of autism. For example, one of the studies has concluded that pregnant women who live within 1.5 km of agricultural land where chemical pesticides are applied experience a 60% increased risk of having an autistic child or a child with developmental delay. The risk was shown to be higher the closer the mother lived to an application site. Different types of pesticides were shown to have different effects, also depending on when during the pregnancy the exposure happened: organophosphates exposure during the last 3 months of pregnancy and chlorpyrifos exposure in the 4th, 5th and 6th month of pregnancy were shown to be most closely associated with increased risk of autism (Shelton *et al.*, 2014).

For students in the natural or exact sciences

In the natural or exact sciences, researchers often use **controlled experiments** to test the hypothesis. In a controlled experiment, the researcher essentially manipulates the value of the independent variable in order to observe the effect is has on the dependent variable. In the meantime, the experiment has to be set in such a way that other variables would not interfere with the outcome. If the experiment is planned and performed well, it actually makes it easier for the researcher to reach valid conclusions, because she does not have to collect such a great number of observations from the real (non-manipulated) world.

Example

If we want to test the effect of irrigation on plant growth, the amount of water poured on the plant would be the independent variable and the height of the plant would be the dependent variable. Control variables can include air temperature, amount of sunlight, plant species, soil type, amount of fertilizers used, etc. In a simple controlled experiment, we can use 10 identical plants growing in identical soil in the same room (thus ensuring that temperature and sunlight are the same for all of them). We would consistently, for a period of time, water the 10 plants using different amounts of water (but always using the same amount of water on the same plant), and we would observe how the 10 different plans grow. On the basis of the quantitative results achieved – the height of each plant and the corresponding amount of water which we used to irrigate it – we can conclude what is the optimal amount of water that should be used to irrigate this plant species if we want it to achieve maximum height.

➔ Testing for alternative explanations

In the complex natural and social world there are often several variables that can be causing the same outcome. Therefore, scientists need to study not just the relationship between their chosen dependent and independent variables, but also the effects of other potential explanatory variables called ‘control variables’ (KKV 1994, 77). In order to isolate the relationship between the dependent and the independent variables from the effects of a control variable, the hypothesis needs to be tested on cases in which the values of the control variable remain the same - if the control variable does not vary, then it obviously cannot cause any variation in the outcome. This is usually done by creating a subsample of the larger sample of cases, ensuring that the control variables are constant in the subsample (della Porta, 2008: 201).

➔ Example

To go back to our example, in order to ensure that it is not genetic factors that are actually causing autism, researchers may decide to study the association between prenatal pesticides exposure and autism in a subsample of children who do not have genetic predisposition to autism (e.g. there is no other family member with autism). If the association holds in this subsample, too, then the impact of prenatal exposure to pesticides on the child’s risk of developing autism is independent of any genetic factors.

For advanced or ambitious students

The ability to control for all other explanatory variables and for random or intervening variables in order to ascertain a causal relationship is one of the greatest challenges in scientific research. It may take decades of repeated experiments by different research teams before a causal relationship is regarded as rigorously tested and verified (albeit never certain). Some of the potential complications during the research process are:

Random variables

To make matters even more difficult, often there are also ‘random variables’ whose value may affect the outcome. These variables are best described as “a chance factor” that cannot be predicted or controlled for.

Multiple causation

In many cases one outcome is caused by the simultaneous or combined effect of several explanatory variables. It is possible that if scientists test for the effect of each of these explanatory variables independently, they would not find any causal relationship because only a combination of variables can cause that specific outcome to occur.

Data and data quality

In principle, researchers need to have a formulated hypothesis before they start collecting data or making experiments in order to test it – otherwise they would not know what information should be collected or what experiments should be made. However, in practice, researchers often need to analyse some preliminary data in order to come up with a reasoned hypothesis in the first place (KKV, 1994: 23). Therefore, the process of collecting data cannot be clearly separated from the process of constructing theory. The golden rule is that researchers should strive to avoid the grave mistake of formulating a hypothesis that perfectly fits the preliminary collected data and then proving this hypothesis with the same data. It is important that they follow up the hypothesis with new data collection and rigorous tests (KKV, 1994: 21).

Data collection can rely on a wide range of methods depending on which style of research the scientist follows. Common methods include statistical models, surveys, randomized experiments, etc. (KKV 1994, 51). Interviews, ethnographic studies, content analysis and similar methods can be used in qualitative research only. In order to be valid, scientific research – whether qualitative or quantitative – should use *explicit and public* methods of generating and analysing data. Researchers should record and report the process through which they collected and processed their data. Ideally, researchers should also make sure that their experiments, data collection and their analysis of the data could be *replicated* by another researcher. If other scholars are not able to assess the validity and reliability of the data, then they cannot assess the validity and reliability of the conclusions either (KKV, 1994: 7-9).

Step 7

Reproduce steps 4, 5 and 6, until there are no discrepancies between observations/experiments and hypothesis. When consistency is obtained, the hypothesis becomes a theory

The theory is a reasoned answer to the research question that usually contains several specific hypotheses. Science tends to be a frustrating field and theories are in fact rarely proven. It is good to remember that the goal of research is not to support the scientist's hypothesis. The goal is to understand a phenomenon better. Results that reject the hypothesis are just as valuable as results that support it.

A good theory should also have some prescriptive power (van Evera, 1997: 21). It should be able to identify causes or conditions that can be controlled or manipulated by scientific activity, policymakers, individuals or the society in order to avoid negative outcomes or to lead to positive outcomes. Prescriptive power is especially important for theories that can improve the wellbeing of society, e.g. economic theories, theories in the field of medicine, theories in the sphere of security studies, etc. Even before a hypothesis becomes a theory, research often gives important knowledge and insights about the world and can be used to improve the wellbeing of people.

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➔ Example

In our example about the link between prenatal exposure to pesticides and autism, many more studies need to be carried out until the hypothesis becomes a theory. Yet, although further studies are underway, researchers have concluded that caution is warranted for women to avoid direct contact with pesticides during pregnancy (Shelton *et al*., 2014).

For advanced students

Theories and complexity

We all know that reality is complex. Sometimes, it is very complex. Complexity generally makes scientific research more uncertain but does not diminish the value and validity of the scientific endeavour. While it may be useful to account as much as possible for the complexity of reality, sometimes the real value of a theory is that it can isolate a limited number of variables and outcomes in order to reach a coherent conclusion and specify a particular and important causal relation[3] (KKV, 1994: 9-12).

ADDITIONAL MATERIAL (FOR LONGER TRAINING SESSIONS OR FOR ADVANCED STUDENTS WITH SPECIFIC TRAINING NEEDS)

TWO STYLES OF RESEARCH: QUANTITATIVE AND QUALITATIVE

> *"[T]he only acceptable point of view appears to be the one that recognizes both sides of reality—the quantitative and the qualitative, the physical and the psychical—as compatible with each other"*
>
> *Wolfgang Pauli, physicist*

Quantitative research relies on numerical data and measurements and uses statistical methods. It is generally uninterested in particular cases and instead searches for general trends, causal relationships and descriptions. It generates a large amount of data on which it bases its conclusions. Quantitative research is typical for the natural and life sciences, but is also used widely in the social sciences, for example in economics and political science.

Qualitative research on the other hand generates non-numerical data. It is used in the social sciences. Instead of searching for general trends and causal relations, it focuses on a few cases of events and phenomena, and tries to understand the reasons for actions and events. It can rely on historical material and interviews. Due to the small number of cases, qualitative research is a valuable exploration into the causes of events but is rarely able to reach conclusive results and even less able to generalize them.

While the styles of qualitative and quantitative research are different, there are nevertheless some basic requirements and rules that are common to both. These common requirements and rules cover many of the elements in the scientific method.

THE ETHICS OF RESEARCH

> *"Relativity applies to physics, not ethics."*
>
> *Albert Einstein*

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[3] Such simplification and isolation may be particularly difficult in the social sciences, where events and phenomena are the result of complex interactions of many causes, chance occurrences, particular conjunction of events, personalities of key leaders, major institutions or social forces.

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Apart from being methodologically sound, scientific research should also always ensure that it respects some ethical rules:

- ⇨ All participants in research (respondents, interviewees, contributors) participate in it voluntarily and are not harmed by the research process or the research results
- ⇨ To the extent necessary, anonymity and confidentiality should be respected when doing research
- ⇨ Covert methods of research should be avoided
- ⇨ Researchers should avoid misrepresentation, inventing data, slack referencing and plagiarism
- ⇨ Research and its results should not harm human beings
- ⇨ Researchers should be accountable to the public regarding the process and results of their research
- ⇨ There are many norms that govern research in order to ensure that it promotes important moral and social values, such as social responsibility, human rights and dignity, animal welfare, law and order, public health and safety.

THE LIMITATIONS OF SCIENCE

> *"Science cannot solve the ultimate mystery of nature. And that is because, in the last analysis, we ourselves are a part of the mystery that we are trying to solve."*
>
> *Max Planck, Physicist*

Science is useful and important. It is a great human endeavour. It will never reach its "end". It will continue to refine and expand our knowledge of the world and the universe, uncovering new questions and puzzles. However, we should never forget that science, like any other human endeavour, has its limits (the list below is based on Teaching the Nature of Science, http://www.indiana.edu/~ensiweb/lessons/unt.n.s.html):

- ⇨ Observations are confined to the biological limits of our senses and the possibilities of human-made technology
- ⇨ Every scientist – event the best one – will always be unconsciously influenced by previous experiences, which in some cases may result in inaccurate or biased observations or conclusions
- ⇨ Science can be performed poorly and can entail mistakes
- ⇨ It will never be possible to know whether we have observed every possible aspect or manifestation of a phenomenon, whether we have considered every possible explanation, or whether we have controlled for every possible factor that may influence the result of scientific inquiry. Scientific knowledge is based only on the available evidence and as such it is never an indisputable fact or truth. The history of science demonstrates that scientific knowledge has been changing over time. Indeed, most scientific conclusions have been disputed and many have been disproved
- ⇨ Science is not democratic or fair. The results of science need not necessarily contribute to building a more just society and they need not necessarily benefit all of us to the same extent
- ⇨ Science can be misused.

Annex II: Model hands-on activity sheet

BULLYING IN OUR SCHOOL

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Target group: Students interested in the social sciences or studying in high schools with specialization in social sciences (tourism, economics, finances, etc.).

Objective: Allow students to explore possible explanations of why bullying (physical or cyberbullying) occurs in their school and what are the possible ways to reduce the incidence of bullying.

Variations

There are several possible variations on this theme that instructors may choose if they feel or know that the change would make the issue more relevant to the particular students. Such variations are:

- Explain the incidence of bullying (in general, rather than in this particular school - higher level of generalization)
- What are the effects of bullying on those that are bullied and those that bully others? What should be done to help those students?
- Why is bullying in our school (or country) on the rise?
- Why is cyberbullying on the rise in our school (or country)?

Implementation: This model activity presupposes that the class instructor has chosen the topic for the students. It also in effect means that the instructor has determined the research question, e.g., "Why does bullying occur in our school?". The students will therefore be instructed to organize in groups and work on applying the scientific method to answer the research question and to then propose actions to reduce the incidence of bullying.

Steps in the activity (it should be kept in mind that the students are working in groups and each of the steps below needs to be taken by each group):

Phase 1: Students are instructed to develop several alternative hypotheses that explain the phenomenon. The hypotheses should be in the following forms:

- ✓ Bullying occurs because of [*cause*]
- ✓ [*Cause*] is contributing to the rising incidence (or continuing existence) of bullying in our school
- ✓ Bullying is not a real problem in our school; instead [*alternative view*, e.g. many students report that they were bullied because now it is a hot topic but in fact they are just referring to conflicts that are quite common among people in this age]

Students should be made aware that they have autonomy in developing the working hypotheses (as long as they are reasonable). In this phase, brainstorming would be a useful method. Students should be instructed to seek consensus within the team. Between 2 to 5 working hypotheses per group is an acceptable outcome.

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Phase 2: Students are expected to make predictions derived from each of the developed hypotheses in the following basic forms:

- ✓ If bullying in our school is caused by [*cause*] we would expect to observe [*prediction*]
- ✓ If bullying in our school is not really a problem but [*alternative view*], we would expect to observe [*prediction*]

Phase 3: Students are expected to plan viable ways of testing the hypotheses (collecting data and using data to draw conclusions). Facilitators should work with the groups to ensure that they are applying the scientific method correctly. Among the possible testing approaches (always depending on the predictions) could be:

- Students can develop a survey among students and teachers in their school to test their hypothesis (e.g. if they hypothesize that playing aggressive video games or seeing violence in films is causing increasing incidence of bullying; or if they hypothesize that aggressive behavior and bullying is not sufficiently strongly penalized by teachers or school authorities; or if they hypothesize that the school has not created proper mechanisms to report bullying; or if they hypothesize that not enough is done to teach tolerance and acceptance of those that are 'different' and 'vulnerable' due to race, ethnicity, sexual orientation or appearance)
- Students can use statistics (e.g. if they hypothesize that bullying is the result of increasing incidence of dysfunctional families they may use national divorce statistics; if they hypothesize that bullying is caused by other social problems in the community, such as increasing poverty or increasing unemployment, they may decide to use statistics about these problems). It should be noted that using statistics may require a more sophisticated approach by students, as it may be necessary to compare statistical data across time or geographic locations (e.g. if they hypothesize that bullying is on the rise due to rising poverty, they may need to compare current data about bullying and poverty with data about bullying and poverty during a previous time period, or data for their region with data from other regions)
- Students can use policy analysis (e.g. if they hypothesize that the government is not addressing adequately the issue of school bullying or other problems in school education that reduce the time and ability of school authorities or teachers to adequately deal with this issue).

Phase 3: Students are encouraged to think of possible solutions to mitigate this problem. They should be instructed to propose alternative solutions for each of the proposed hypothesis, i.e. In case Hypothesis 1 is supported by the data, what would be the possible solutions? In case Hypothesis 2 is supported by data, what would be the possible solutions?, etc. This phase would allow students to grasp the prescriptive aspects of theory and science and to practice the skills to utilize these aspects in the attempt to improve current situations. In the process, they will learn to appreciate the importance of science for improving people's lives (including their own lives) and solving societal problems. They will also realize the importance of basing both policy and personal decisions on sound (possibly scientific) evidence. Ultimately, this phase will help promote scientific citizenship and active citizenship in general.

Phase 4: Students prepare and deliver presentations of their groups' results

This phase of the activity should typically focus on sharing the results among the different working groups. In a short training session, setting more ambitious goals is probably not advisable as students will simply not have sufficient time. If the short-training format is chosen, the focus should be on the previous phases, with this phase generally allowing the teams to benchmark again each other. Students should be encouraged to use visual representation to communicate their results, notably on flipchart paper. Students should also be instructed to respect the time limits set for each presentation.

In longer training sessions, more specific attention could be paid to the form and quality of presentations. Such a focus would be justified in particular for students who have a strong interest in STEM, as it introduces them to the problem of science communication.

Phase 5: Students are invited to engage in reflection and discussion:

- ✓ Students are invited to critique the other groups' results from the point of view of the scientific method, pointing out any fallacies and inconsistencies. This phase is extremely important as it can provide feedback to the participating students. Students should be made to understand that critique on the basis of normative issues or values (including such important ones as fairness, equality, justice, citizenship rights, democracy, liberal economic development, etc.) is only applicable in when critiquing the proposed solutions, while the critique of the hypotheses and their testing should be based solely on the scientific validity of the approach and methodology.
- ✓ Students should be encouraged to share their experience with applying the scientific method, focusing on what they perceive as the benefits of this method and what they perceive are the limitations or drawbacks of this method.

It should be noted that in short training sessions, 10 minutes might be extremely insufficient for both tasks. Instructors who want to provoke more in-depth discussion on any of those issues may need to choose to focus on only one of them.

Training support material for facilitators/instructors in longer training sessions: Designing, carrying out and analyzing surveys

Designing, carrying out and analysing surveys can be an especially valuable skill to develop in students. Surveys are widely used and many professions require such skills. Below, we provide introductory theoretical material that instructors and facilitators may need if the hands-on activity includes survey design.

Surveys allow social scientists to collect or determine the opinions, beliefs or other characteristics of a section of the population, which is referred to as 'the sample'. The sample is selected so that it represents a larger population – this is called the target population.

The implementation of a survey consists of asking questions through structured or semi-structured interviews or questionnaires, collecting data on the responses, and reaching conclusions based on the analysis of this data. On the basis of the collected data, surveys generalize about the opinions, beliefs or other characteristics of the larger target population from which the sample was selected.

When designing a survey, social scientists need to consider several aspects:

- ⇨ What will be the research objective(s) and the research question(s)?

- ⇨ Which concepts will be measured and how they are going to be operationalized through empirical indicators? `
- ⇨ What will be the specific questions that will be included in the survey questionnaire? Key elements to consider are: question wording, order of the questions, question context, choice of response categories, etc. (Leeuw and Hox, 2008: 5)
- ⇨ What will be the mode of the survey?
  - *supervised by the researcher* – face-to-face and telephone-based surveys

    or

  - *unsupervised by the researcher* – self-administered questionnaire (mail-back or internet-based) (Johnston, 2008: 386)
- ⇨ What will be the sample? How will the scientist ensure the representativeness of the survey sample and the results?

  When selecting the sample, the social scientists should consider the target population and determine how many respondents are enough to achieve a representative sample of this population, as well as how they should be selected. Avoiding *sampling error* is a major challenge because only a portion (sample) of the population is investigated, while the results need to be generalized for the whole target population. While a larger sample is always more representative, sample size often needs to be reduced due to budgetary or time constraints. Depending on the objectives of the survey, respondents can be chosen randomly or on the basis of more complicated sampling schemes, such as cluster sampling or stratification (Leeuw and Hox, 2008: 9).

  Researchers also need to avoid *coverage error* that results from choosing the sample in such a way that some members of the target population have a zero probability of being included in the sample (Leeuw and Hox, 2008: 7).

  Usually, social scientists need to solve two basic problems when designing and implementing surveys – *prior selection bias* and *nonresponse.*

  Selection bias affects the initial choice of the sample at the stage of survey design. It can be the result of under-coverage of a particular group within the survey. For example, a voter survey may be biased in favour or male voters if the number of male and female respondents does not reflect the ratio between women and man in the target population. A selection bias can also result from the chosen mode. For example, if an internet survey is carried out, there is bias in favour of internet users. Finally, a selection bias can also be the result of over-representing a type of respondents that are more likely to give a particular answer. For example, in a survey focused on the future demand for a product, loyal customers of the firm are more likely to show interest in the product than other consumers. Selection bias is perhaps the greatest challenge a researcher faces when designing a survey. It can never be fully eliminated. A good survey should estimate the selection bias when presenting the results or should at least describe in detail how the survey was carried out.

  Nonresponse is a problem at the stage of implementing the survey. It is of two types: unit nonresponse (when the unit fails to respond at all) and item nonresponse (when there is lack of response to a specific question in the survey) (Leeuw and Hox, 2008: 10). Unit nonresponse within an otherwise representative sample essentially has the same effect as reducing the sample or making a non-representative sample – it diminishes the relevance of the results. A significant nonresponse error occurs when the non-responding units are different from the responding units in a way that could distort the conclusions from the survey (e.g. if most of the non-respondents are women, this would in effect mean that the results are non-representative as they would be distorted in favour of responses given by men).

The response rate is usually affected by how the respondents are contacted. Non-personal modes of administering the survey typically achieve lower levels of response than personal modes, such as a face-to-face interview. Yet personal modes require a lot of time and effort and therefore they typically have more limited coverage to start with (Johnston, 2008: 389-340; Silbergh, 2001: 117). A response rate of 80% or above is indicative of a successful survey (Silbergh, 2001: 117).

⇨ What time period will the survey cover?

Repeated measurement through re-running the survey leads to more reliable results. However, in conditions of typical time and budgetary constraints, repeated measurement can be achieved only by reducing the number of respondents, which limits the representativeness of the sample. Researchers need to consider in each individual case whether reliability of measurement should be prioritized over sample representativeness. In terms of the reliability of the conclusions, a one-off survey with a larger sample would typically be considered superior to repeated measurement based on a smaller sample.

⇨ Will the survey rely on structured or semi-structured interviews or questionnaires?

Structured interviews and questionnaires ask all respondents to answer the same questions in the same order. This approach standardizes the stimuli that the respondents face and can thus ensure that variation in the response is not the result of the way the survey was administered (Silbergh, 2001: 114). Semi-structured interviews and questionnaires include a certain number of non-standardized questions and can complicate interpretation and measurement, but will possibly provide more valuable and detailed information.

⇨ How will the scientist ensure the representativeness of the responses?

Usually, social scientists need to solve two basic problems in this regard – quality of the responses and the distribution of responses across the extremes of opinions. Failure to do this leads to measurement error. Measurement error can result from a poorly designed survey questionnaire, from failure of the respondents themselves to provide a quality response and from the method of data collection. The presence of an interviewer in supervised surveys is an additional source of error (Leeuw and Hox, 2008: 11).

Above all, the questions included in the survey questionnaire have to be clear and unambiguous so that there cannot be different interpretations of the questions. Mail-back and internet surveys fare pretty well in ensuring quality of response. In supervised interviews, the interviewer can ask for clarification which can significantly increase response quality, but the very presence of the interviewer can also distort the results by discouraging 'socially unacceptable' responses. The interviewer may influence the respondent in many other subtle ways or may misinterpret or misrepresent the questions when providing additional information. The rule of thumb is that if the survey includes sensitive questions, non-supervised survey modes are the better option (Johnston, 2008: 393-395). Open-ended questions, too, may increase the quality of response by allowing for more detailed and nuanced responses, but at the price of complicated measurement. They necessitate qualitative evaluation, which makes such surveys more prone to errors of interpretation (Silbergh, 2001: 114-115).

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Annex III: Co-Creation

University Students

Selection	
The following university students can be involved in the design and delivery of the activity: - Students in their second year of studies, or further in their studies. Graduate students in their first year of PhD studies are the best choice since they are anyway focused on research design - Students should be selected by the faculty member responsible for the activity and should have worked with this faculty member before (in class or in educational outreach activities). The selected students should stand out for their science communication skills rather than their excellence and academic achievement per se.	
Role (in order of relevance)	**Guidance**
Pedagogical co-designers of learning, teaching and assessment; facilitators in hands-on and lab experiments	The selected university students: - can work together with high school students during the practical activity in order to help with the decision making process and the research design process - should participate in the assessment of student performance during the activity and in the evaluation of the effectiveness of the training - should be actively engaged in the self-reflection phase, staying with the team in which they worked.
Mentors of SE VET students	The selected university students can be asked to share their contacts with bright or motivated high school students who may want to learn more about the topic or visit the university.
Consultants in planning and designing the learning and teaching process	The selected university students should be fully engaged in the design of the hands-on activity in order to select a topic that is closer to young peoples' interests. Students can be given the task to prepare the Power Point presentation for the activity, as well as any handouts and supporting materials. They should, however, do this on the basis of clear instructions from the faculty member who will lead the course.
Co-researchers contributing to subject-based research	The engaged university students can be asked to collect and present examples of the application of the scientific method that would

	be suitable for younger people.

High School Teachers (supporting role is suitable for teachers in any science area)

Consultants in planning and designing the learning and teaching process	The accompanying teachers should have the leading role in selecting trainees from among the students. They should be approached in advance and consulted about the relevance of the presented examples and the suitable level of difficulty of the theoretical presentation (in view of the intended group of trainees). Special attention should be paid to the selection of relevant and accessible examples demonstrating the scientific method. Teachers should be consulted about the best way to draw parallels and to link the content of the course to the compulsory study programs.
Pedagogical co-designers of learning, teaching and assessment; facilitators in hands-on and lab experiments	The accompanying teachers should work together with high school students during the practical activity in order to help with the thinking, brainstorming and decision making process and the research design itself. The accompanying teachers should be the primary source of feedback about the effectiveness of the training. They will also be in the best position to assess the performance of their students. Teachers should play a central role in maintaining discipline during the activity.

University-high school partnerships

This course in particular would be a suitable addition to the study programs in any school, not necessary a school with a STEM profile. It can also be the beginning of a series of extra-curricular courses on a variety of scientific topics. If there is such an interest, contact between the accompanying teachers and the university should be made well in advance and the course should be planned as part of a larger-scale activity. Possible topics for further courses should be outlined in advance. The course can be combined with public lectures at the university to which the high school students can be invited. One particular high school teacher or administrator and one particular faculty member should be tasked with the organization and should act as contact persons and "boundary spanners". For further collaboration to be planned, it is advisable that an educational manager from the hosting school attend (part of) the course in order to witness the effectiveness of the training. If that is not possible, then a report of the achieved results and the satisfaction of students should be presented to the school management together with a technical and financial proposal for further collaboration.

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