Surrounded by Science

Learning Paths towards Science Proficiency

Research and Innovation Action in the European Union's Horizon 2020 Programme
Grant Agreement no. 101006349

Deliverable 2.1

Research methodology and plan

Editor	Natasha Dmoshinskaia (UT)
Date	31 January 2022
Dissemination Level	Public
Status	Final

The Surrounded by Science project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement no. 101006349. This publication only reflects the author's view and the European Commission is not responsible for any use that may be made of the information it contains.

The Surrounded by Science Consortium

Participant No. *	Participant organization name	Short name	Country
1 (Coordinator)	Universiteit Twente	UT	Netherlands
2	Ellinogermaniki Agogi Scholi Panagea Savva AE	EA	Greece
3	European Physical Society Association	EPS	France
4	Nuclio Nucleo Interactivo de Astronomia Associacao	NUCLIO	Portugal
5	Fondazione IDIS-Citta della Scienza	IDIS	Italy
6	The Lisbon Council for Economic Competitiveness and Social Renewal asbl	LC	Belgium
7	Weizmann Institute of Science	WIS	Israel
8	Norges Teknisk-Naturvitenskapelige Universitet	NTNU	Norway

Contributors

Name	Institution
Natasha Dmoshinskaia	UT
Sherman Rosenfeld	WIS
Tessa Eysink	UT
Sofoklis Sotiriou	EA
Angelos Alexopoulos	EA
Pavlos Koulouris	EA
Hannie Gijlers	UT
Luigi Cerri	IDIS

Legal Notice

Executive Summary

The current deliverable describes the research methodology of the Surrounded by Science project in general and the tasks of Work Package 2 in particular.

The starting point of the Surrounded by Science project is a growing understanding that STEM learning should not be and is not limited to formal settings only. Informal STEM learning activities can play an important role in forming young people's interest in science, their understating of science phenomena, applying scientific thinking for everyday-life situations and developing their science identity. Based on this approach, the project's guiding research question is *How can informal STEM learning activities contribute to the development of science proficiency, including in formal science learning settings?* The experience of previous projects in the area of informal STEM learning forms the bridge to the expected outcomes of the current project.

To dive more deeply into the subject, the key concepts of the project are introduced and explained, showing the direction in which the research will go. These concepts include informal STEM learning, learning ecology and learning pathways, informal STEM learning contexts and activities, and science proficiency. Learning science happens a lot outside the classroom (informal STEM learning) when young people visit a zoo, watch a documentary or participate in a science club, which are all examples of informal STEM learning activities. Such activities can be grouped to form learning contexts: outreach programmes, designed environments and media/technology products. Interacting with activities from different informal STEM learning contexts happens in a bigger environment (learning ecology) and forms a kind of an individual journey (a learning pathway) towards science proficiency. Science proficiency is seen as a set of strands that relate to affective outcomes (e.g., being interested in and excited by science) and cognitive outcomes (understanding scientific context and knowledge). Science proficiency allows young people to achieve goals and aspirations in science as well as to be able to understand the world around them and be a responsible citizen.

Having clarified the key concepts, the deliverable presents the conceptual approach of the project's research methodology, while paying attention to the upcoming tasks. The role of this deliverable as a roadmap for further work in this work package and in other work packages concludes the document. The examples of such contribution to the work of other work packages can be seen in shaping the research implementation (WP4) based on the general approach to conducting research, and in informing the development of the digital toolbox (WP3) and the impact assessment (WP5) by identifying the research perspectives for assessing the role of iSTEM learning activities in forming science proficiency.

Table of Contents

1 Introduction

The current deliverable describes the research methodology of the Surrounded by Science project in general and the tasks of Work Package 2 in particular.

The goal of the document is to provide an approach to the research methodology of the project and to suggest conceptual ways to complete the upcoming tasks. The deliverable defines the conceptual base of the project, while future deliverables will zoom into the tasks and provide detailed information about the particular methods and techniques. As such, this deliverable is central to the work of other work packages and gives guidance to them.

The document starts with providing a big picture of the context in which the Surrounded by Science project operates, as well as its ambitions (Chapter 2). To do that, it presents the guiding research question, the problem motivating this question, prior work in this area, and the expected contributions of the project.

Chapter 3 explains the project's key concepts: the nature of informal STEM (iSTEM) learning activities, learning ecology and learning pathways, iSTEM contexts and activities, and science proficiency.

Chapter 4 presents an example of an iSTEM learning pathway including different contexts and activities. This example shows our view and ambition on the project and serves as a link to the next chapter. Chapter 5 gives an overview of the research methodology for the entire project, with more details given for Phase 1 and specifically to the tasks of Work Package 2. The research activities relate to four different research perspectives and are carried out by different work packages, as described.

Finally, the Conclusion (Chapter 6) summarises the main connections of this deliverable to other work packages and shows how Work Package 2 outcomes will inform the work of other work packages, such as WP3, WP4, WP5 and WP8.

2 The promise of informal STEM learning

The purpose of this chapter is to provide the “big picture” of the Surrounded by Science project. The guiding research question of the Surrounded by Science project is: ***How can informal STEM learning activities contribute to the development of science proficiency, including in formal science learning settings?***

This research question invites a series of clarifications that are discussed in the sections that follow: (1) the problem motivating this research question, (2) prior work in this area, and (3) the expected contributions.

2.1 The problem

The project in general and its research question in particular are motivated by the growing understanding that formal science learning in schools cannot and should not be society’s only vehicle for developing the scientific competencies of its citizens. In the words of a seminal report:

> *Schools cannot act alone*, and society must better understand and draw on *the full range of science learning experiences* to improve science education broadly (NRC, 2009, p. 12, emphasis added).

The identification of this problem by decision-makers has been gradually developing for several decades (e.g., Eshach, 2007; Fallik, Rosenfeld, & Eylon, 2013; Hofstein & Rosenfeld, 1996). For many years, both public and policy makers have equated the notions of “science education”, “science learning” and “schools”. But today it is clear that learners of all ages spend a relatively small percentage of their lives in a classroom; it is estimated that 95% of the science that people learn comes from out-of-school environments (Falk & Dierking, 2010). This learning is “free-choice” in nature, which means that it is in the domain of informal STEM learning activities.

This situation poses a challenge: how to identify and characterise effective activities from out-of-school science environments, and how to assess their contributions to science proficiency. This challenge is being addressed by this project.

2.2 Prior design work and activity assessment

Recently, there has been a great deal of work in “bridging the gap” between formal and informal learning environments in STEM, i.e., in connecting science museums and other out-of-school science settings with school science, connecting art and science, as well as in developing repositories of activities that promote many different learning pathways. Examples of such related initiatives in Europe are four recent projects: SySTEM 2020, CREATIONS, PATHWAY, and COMnPLAY. The Surrounded by Science project intends to build on these four EU-supported projects in two ways: using them as resources to identify (1) possible examples of best practices regarding informal STEM learning activities, and (2) possible assessment instruments to be used or modified for assessing these types of activities. In the paragraphs that follow, these four initiatives are described, and suggestions are formulated about how the Surrounded by Science project can build on them.

The goal of SySTEM 2020 (https://system2020.education/the-map/) was to map iSTEM initiatives beyond the classroom that are designed for learners aged 9-20, many of whom come from minority, economically disadvantaged and migrant communities (Brown, Kapros, & Roche, 2021). For example, in Traveling Scientific Microexhibitions, ready-made exhibition kits were distributed to schools for display, which helped to increase scientific literacy, trigger learners’ active involvement and promote scientific vocations by making science accessible and engaging. These Microexhibitions addressed transdisciplinary content like climate change, and were a successful strategy to collaborate with schools and education communities located in remote villages. SySTEM

2020 has mapped iSTEM initiatives from 19 countries that can provide examples of best practices for the Surrounded by Science project. SySTEM 2020 has also developed and tested several assessment tools for these activities that may be helpful in the construction of our assessment tools regarding iSTEM activities. For example, the Experience Sampling Method (ESM) was composed of time-sensitive, consecutive and experience-triggered micro-surveys that assessed variables such as interest in science, the acquisition of new knowledge and the level of activity engagement, aspects that are also relevant to the Surrounded by Science project. In addition, the Surrounded by Science project can learn from the development and use of this assessment instrument. For example, in the usability and comprehensibility phase of developing this instrument, it became clear that the English word “science” has a slightly different and broader meaning than the German literal translation of "Wissenschaft"; these language differences need to be taken into account in the final instruments, written in the languages of the different partners in the project (Zolotonosa & Hurley, 2021).

Dance, music and the fine arts were all associated with cross-disciplinary thinking in the CREATIONS project (http://creations-project.eu/resources/creations-resources/). This project focused on STEAM activities, with an “A for Art” added to the traditional STEM framework. For example, in the “Learning Science through Theatre” initiative, learners created a bridge between drama and science by writing and presenting plays with each play’s characters, costumes, music and dance, representing potential ways of interpreting learners' scientific inquiries. In this effort, both science and art were integrated, based on participants’ creativity and observation skills (Smyrnaiou, Georgakopoulou, Sotiriou, & Sotiriou, 2017). Surrounded by Science can build on the CREATIONS project by including their STEM/STEAM activities as possible examples of best practices of iSTEM activities that represent scientific concepts in innovative and imaginative ways. For example, “embodied learning” is a contemporary pedagogical theory of learning, which emphasizes the use of the body in the learning process; within the context of STEAM, this approach may provide inspiration about how to assess a very intangible and complex construct, such as creativity. (Smyrnaiou, et al., 2017).

The aim of the PATHWAY project (http://pathway.ea.gr/content/pathway-best-practices) was to develop a standard-based approach to teaching science by inquiry by various means, including the connection of out-of-school science learning and science learning in schools. For instance, in the Farm-Based Inquiry Science, farm educators worked with teachers to create and implement inquiry-based sessions -- which are closely linked to the formal school curriculum -- for elementary school students. The focus of the farm sessions was hands-on, active and engaging learning through a carefully structured program that allowed learners to develop their critical questioning and science inquiry skills. Thus, the PATHWAY project promoted inquiry-based science teaching and learning with science teachers throughout Europe and has developed guidelines for the introduction of inquiry-based approaches in school science. The main outcome of this project was to show the process of interconnecting formal and informal learning settings offering inquiry learning experiences across different settings (Sotiriou, Bybee, & Bogner, 2017). This contribution is important to the current project, since it supports the main focus of Surrounded by Science, in the sense that learners move through different learning contexts on their way to develop science proficiency.

Another EU-funded project, COMnPLAY (https://comnplayscience.eu/) aimed to better understand the ways that STEM/STEAM learning activities – particularly related to coding and making -- can engage learners and develop their technological skills in out-of-school settings. The COMnPLAY project’s Inventory of Practices (https://comnplayscience.eu/app/practice) gave access to these types of technology-oriented STEM learning activities that can provide valuable insights to the Surrounded by Science project about how learners can acquire coding and making practices in out-of-school settings (Tisza, et al., 2020). For example, in the “Programming Circus”, children aged 8-9 years with little if any previous coding experience became familiar with the visual programming environment Scratch and engaged in their own projects. In this way, young children learned that they can use computers not only as users but also as creators (Simon, Geldreich, & Hubwieser , 2019).

These four EU-funded projects illustrate the growing interest in bridging between formal and informal STEM learning settings and activities, for the purpose of advancing science proficiency. A more detailed analysis of the resources of these projects – and others like them -- will accompany future deliverables (e.g., D2.2, D5.1).

2.3 Expected contributions

The Surrounded by Science project plans to reach beyond prior design and implementation by setting its main goal as the in-depth assessment of how informal STEM learning activities can contribute to science proficiency as described later in this deliverable. The project endeavours to better understand the promise of informal STEM learning and to apply this understanding, also in schools, by investigating a series of guiding sub-questions: Why are informal STEM learning activities so motivating? Do they also lead to more positive attitudes towards science? To what degree, if any, do they influence people's knowledge and skills? And if not, can these activities be adapted in such a way that they do? How might these activities better relate to formal schooling and how might activities from both contexts complement or strengthen each other? How might informal STEM activities be used to support people in acquiring a scientific way of thinking, so that they can understand and correctly use all scientific information to which they are exposed? How might informal STEM activities support the open schooling strategy of the EU, where schools in cooperation with external stakeholders share the responsibility for youth learning? How might these activities be integrated into wider STEM learning ecologies (Bevan, 2016; Dierking Falk, Shaby, & Status, 2021)? How might informal STEM activities increase understanding of the relevance of science and technology to learners' daily lives and communities? How might they increase young people's confidence and skills to intervene as citizens on science and technology issues?

The expected contributions of informal STEM learning activities *on learners' science learning* include:

- Increasing learners' engagement, excitement, and interest in STEM-related phenomena (i.e., science engagement);
- Expanding the ways that learners think of themselves as science learners, as someone who cares about, uses and sometimes contributes to science (i.e. science identify);
- Contributing to learners' understanding of the relevance of STEM to one's everyday life;
- Advancing STEM learning that will help young people make better choices as citizens (including career choices) in a society where science and STEM are increasingly relevant; and
- Increasing young people's confidence to participate in decision-making for science-related matters (i.e., science citizenship).

In addition, the project expects to make contributions, *in more general terms*, by:

- Further developing the theory and practice of assessing different types of informal STEM learning activities, based on the work of earlier initiatives such as SysTEM 2020 (Zolotonosa & Hurley, 2021);
- Bridging the gap between formal and informal science learning settings;
- Expanding the spectrum of STEM learning activities by for instance including technology-based activities (e.g., coding, robotics, and making practices), as demonstrated by the CREATIONS and COMnPLAY projects (Smyrnaiou, et al., 2017; Tisza, et al., 2020);

- Demonstrating how informal STEM activities can contribute to the *integration* of two or more STEM disciplines;
- Promoting the view to *all* science educators that science learning can happen anywhere and at any time, and that every experience – inside or outside the classroom can be linked to learning pathways that develop science proficiency, as demonstrated also by the PATHWAY project (Sotiriou, Bybee & Bogner, 2017);
- Establishing a healthy dialogue between stakeholders from both learning settings, to develop an "accreditation mechanism" of informal STEM settings, for use by schools.

It is interesting to note that many of these expected contributions are very difficult to implement in schools, due to the way schools operate and are organised; these expected contributions seem to be more possible to implement in informal STEM learning environments.

The Surrounded by Science project will address its main research question and sub-questions through the design of an appropriate research methodology. Before discussing the project's methodology, it will be useful to understand the project's major concepts. These concepts are discussed in the following chapter.

3 Overview of the Surrounded by Science concepts

This chapter aims at introducing the key concepts used by the project, such as informal STEM learning, learning ecology and pathways, informal STEM learning contexts, and science proficiency.

3.1 Informal STEM (iSTEM) learning

In order for society to develop a wide network of public science-learning experiences – and not to rely solely on science learning in classrooms – it is important to recognise the contribution of learning experiences that originate in settings outside schools, such as zoos, aquaria, science centres, botanical gardens and nature centres, digital learning and gaming, science fairs and science festivals, broadcast media and the like.

Some researchers have drawn various distinctions between science learning outside and inside the classroom. The activities outside the classroom are often seen as more "free-choice," it is shown not only in the fact that learners can choose what and when to do, but also that learners have more autonomy and control over their own learning while being engaged with an activity (Falk & Dierking, 1998 and 2019). Such responsiveness to the development of learner's interest, learner agency and science identity are often highlighted as being central in out-of-school activities.

Several different terms have been used for these learning experiences, e.g., out-of-school, free-choice and informal science learning (ISL). Also, sometimes a distinction is made between non-formal learning (e.g., that occurs in non-school institutions, such as science museums and maker spaces, due to an intentional choice) and informal learning (e.g., that occurs in every-day life, at work, at home and in leisure time, even without an intentional choice).

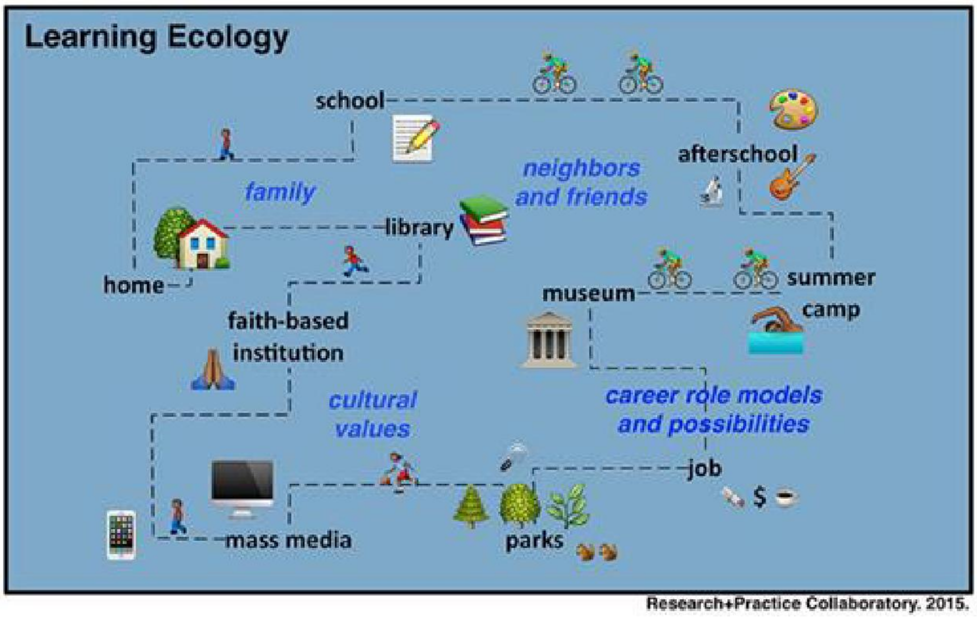
In the Surrounded by Science project, the term "**informal STEM learning**" (abbreviated as iSTEM learning) has been chosen to describe these learning experiences and settings, both within and outside of non-school institutions. In literature, iSTEM learning can be used in one of two ways: (1) as a description of the learning activities relating to any other the *STEM fields*, i.e., science, technology, engineering (including the field of computers), and mathematics, and (2) as a description of the *integration* of two or more of these fields (Mejias et al., 2021). The project will attempt to highlight both of these types of learning activities, with a preference for promoting the integrated understanding.

3.2 Learning ecology and learning pathways

The current situation with formal and informal STEM learning mentioned in the previous chapter seems to indicate a necessity to bridge the gap between the two learning environments by developing an appropriate catalysing process: A connected science learning ecology where youth can encounter a wide range of learning experiences that could lead to future opportunities in personal, academic, professional, and civic realms. According to Bevan (2016) a **learning ecology** is "the physical, social, and cultural context in which learning takes place". Learning ecologies are similar to the natural ones not only in a way that they consist of elements that interact with each other, but also in a way that the elements of which they consist are different for different people. These elements may or may not include science museums, libraries, social media and science programmes (see Figure 1 for an example).

This vision requires educators and organisations to think beyond the bounds of their own institutions to consider how collective action at the level of networks can provide opportunities and address inequalities in a way that more isolated efforts cannot. When discussing how youth might thrive in such an ecology—and what sort of interventions we can develop to help them do so—the idea of pathways (Sotiriou, Bybee, & Bogner, 2017) has often come up as a useful metaphor that invites us to consider youths' "learning lives" over time and across the many contexts (e.g., home, school, community organisations, science centres and museums, web and social media) where learning may occur. While there are many different ways to productively conceptualise such pathways, we simply invoke pathways as a metaphor for thinking about ways to provide structure to youth experiences – learning pathways – how they might “connect to” or “build upon” one another and thus allow a young person to pursue goals that require extended engagement or persistence across multiple contexts and learning opportunities. Learning pathways take many forms influenced by emerging research and discoveries, changes in the needs and interests of society, and changes in personal interests or opportunities. Some individuals describe their learning pathway as an upward trajectory, pointing towards a clear goal. Others describe their pathway as a more irregular line influenced by learning opportunities they encounter. In any case, we refer to an individual’s **learning pathway** as a journey including, among other things, combinations of academic work, internships, workshops, use of online platforms, participating in field trips, reading books, watching documentaries, or learning from a colleague or mentor (see Figure 1).

Figure 1. *A graphical representation of the Learning Ecology that describes the learning paths of individuals in the framework of school and informal STEM learning activities (Bevan, 2016)*

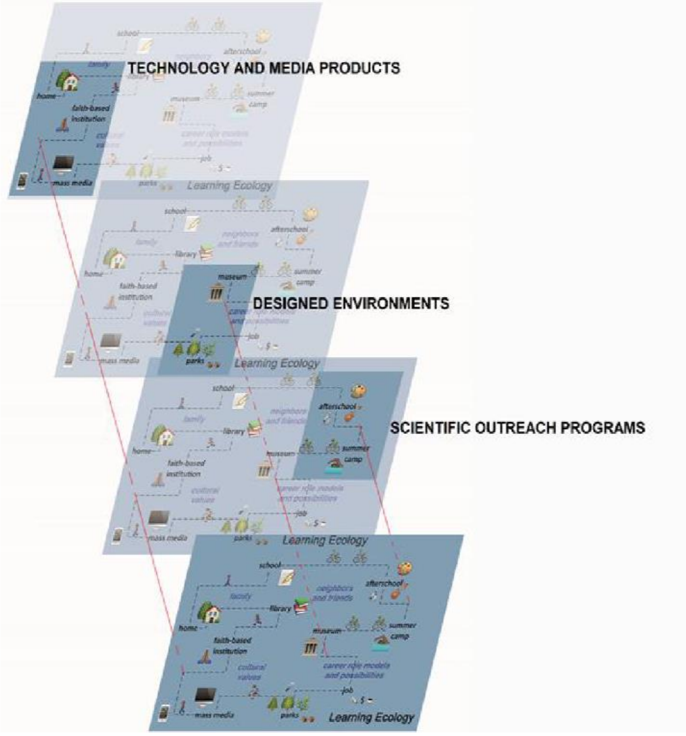


Research+Practice Collaboratory. 2015.

3.3 iSTEM learning contexts and activities

The Surrounded by Science project identifies iSTEM learning as the outcome of the individual’s engagement with activities in **three learning contexts** (see Figure 2).

Figure 2. *Three contexts of informal STEM learning activities contributing to the general science learning ecology (adopted after Bevan, 2016)*



These science learning contexts are characterised by diversity, redundancy, and local adaptations and can contain a wide variety of activities, across a range of institutions and places, allowing individuals to engage with science in different and multiple ways (see Table 1).

Table 1. *The three learning contexts of iSTEM activities, along with the forms of learning supported by each context, their educational objectives and examples*

Contexts	**Supported forms of learning and educational objectives**	**Examples of settings**	**Examples of activities**
Scientific Outreach Programmes	*Guided Inquiry* (focus on scientific content knowledge, scientific reasoning skills, and reflection on science and scientific processes)	Universities, science museums, schools, community centres (non-formal education)	Research Facilities Outreach Programmes Science Clubs Contests Citizens Science Projects Summer Schools Science Fairs
Designed Environments	*Contextualised Learning* (focus on motivation, interest in science, and interest in pursuing a science-oriented career)	Zoos, botanical gardens, science museums, etc. (non-formal education)	Real-life and virtual visits to exhibitions, zoos, botanical gardens, museums and science centres
Technology and Media Products	*Incidental and Free Choice Learning*	Digital settings, such as websites and podcasts, used at home or during free time (informal education)	Websites Videos / YouTube Simulations Games Apps

The first science learning context concerns **scientific outreach programmes**, which refers to coherent programmes designed and organised by out-of-school organisations and including a curriculum that addresses the main activities of the organisation. The activities in this context are typically focused on making information that is available at the organisation accessible and understandable for the wider public. Reflecting this aim, the curriculum and activities focus primarily on scientific content knowledge, scientific reasoning skills, reflection on science and scientific processes, and developing a science identity. Most of these programmes are based on the inquiry approach to demonstrate how science works. Examples of learning activities in this category include after-school programmes, summer courses, research facilities outreach programmes, citizens science projects, focused programmes in museums and science centres, making and tinkering programmes, field trips, contests, etc.

A specific example of an outreach programme is “A virtual visit to VIRGO experiment – The discovery of gravitational waves” (http://www.frontiers-project.eu/demonstrators/virtualvisit/). The programme consists of several activities with the goal to make science closer to learners by giving them an opportunity to see and learn the basic principles of a state-of-the-art piece of equipment that is used by real scientists to observe gravitational waves. Participants not only have an opportunity to see how it works and what problems it can help solving but also talk to scientists who work with it.

The second science learning context that we distinguish in the current project concerns **designed environments,** which refers to environments designed by out-of-school organisations, that aim to provide specific information or experiences and which are related to family or leisure. Typically, engagement is short-term and occasional having fun is considered an important goal. Contextualised learning and engagement are the main characteristics of the learning activities that belong to this learning context. Examples include visits to exhibitions in museums and science centres, botanical gardens, zoos, planetariums, aquariums, and other thematic parks.

A specific example of a designed environment is a virtual visit to the Museo Galileo in Florence, Italy (https://www.museogalileo.it/en/museum/explore/permanent-exhibition/450-the-museo-galileo-on-google-street-view.html). This virtual tour allows visitors to “walk” down the halls of the permanent exhibition and the museum library and includes around a thousand objects showing the history of science in general, and of Galileo’s discoveries in particular. The goal is to make the museum collection more accessible for people in different places and with different abilities. Such a virtual tour is even more attractive in the time of the pandemic as travelling and visiting cultural places is not always possible.

The third science learning context concerns incidental and free choice learning through **technology and media products**, which in the current project refers to on- and offline products that out-of-school science organisations develop for the public, and which rely on the expertise and the responsibility of the organisations. These products can be either stand-alone or related to a scientific outreach programme or designed environment. In the latter cases, they can be used to prepare participants or visitors or to extend the impact of the programme or visit over time. Examples of learning activities in this category are connected to mobile apps, games, simulations, videos, websites, post-visit web experiences, follow-up mail contact, and books.

A specific example of a technology product is the ‘Explore at home’ area of the website of the Dutch Science museum in Amsterdam – Nemo (https://www.nemosciencemuseum.nl/en/explore/). This area presents a wide collection of various activities and it is completely up to visitors to decide which ones and how many they want to complete. Users can engage in this website to learn interesting facts about science and scientists (e.g., Can you see bacteria?), get instructions on conducting experiments at home (e.g., Sail a balloon boat) or test their knowledge (e.g., Which of the dots in the middle is the largest?). The website is targeted for schoolchildren but is also useful for adults.

As activities can be part of a larger programme or can be stand-alone activities, we, therefore, make a distinction, within each context, between programmes (a coherent set of activities that belong together) and activities. A representation of the connection between contexts, programmes and activities is presented in Table 2.

Table 2. *An example relationships between contexts, programmes and activities*

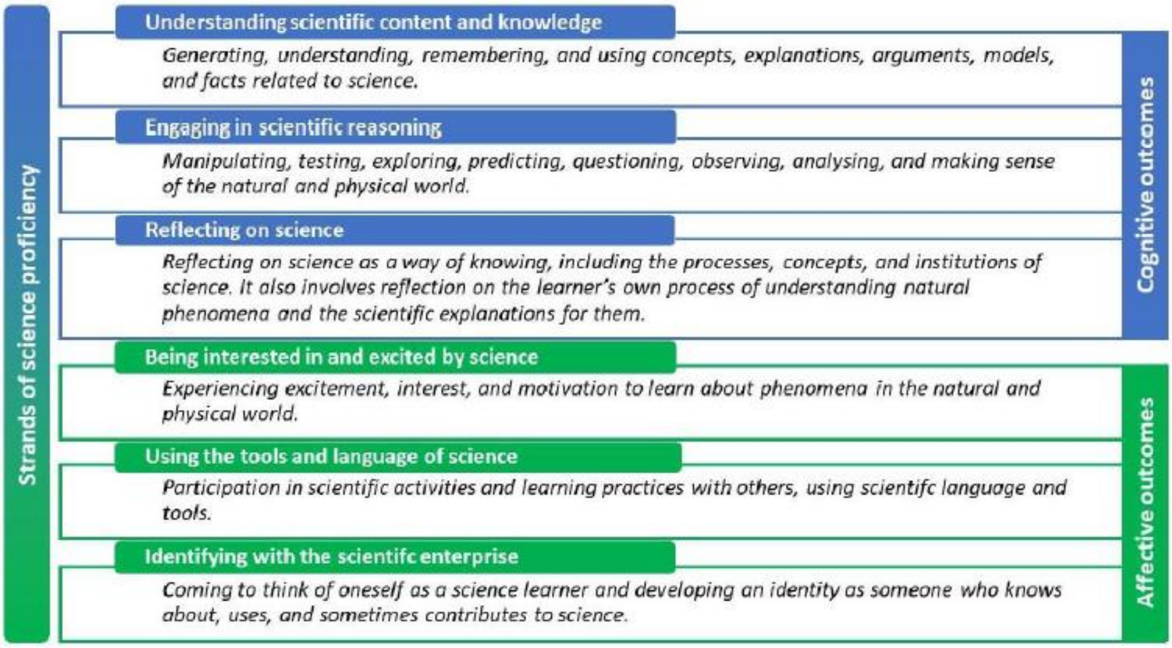
Context	Programme	Activity
Scientific Outreach Programmes	The discovery of gravitational waves (a virtual visit to the VIRGO experiment site)	Collecting scientific information about gravitational waves and methods of observing them
		Watching a video introduction on Virgo optical scheme
		Treasure hunting inside the interferometer experimental building
		Discussing modern challenges with real scientists
		Preparing a final report
Designed Environments		Taking a virtual tour to the Galileo Museum
Technology and Media Products		Reading short texts with interesting facts about science on a university website
		Conducting an experiment at home following the instructions on a research centre website
		Doing quizzes about non-intuitive facts about science on a museum website
		Listening to a podcast about modern technology on a science organisation website

3.4 *Science proficiency*

The Surrounded by Science project investigates iSTEM learning occurring through participating in out-of-school science activities. In particular, it aims to assess how such activities can contribute to the development of science proficiency. **Science proficiency** refers to the development of specific competencies that are necessary to achieve goals and aspirations in science as well as be able to understand the world around us and be a responsible citizen.

The project uses a model of science proficiency consisting of six strands (Figure 3).These six features of science learning were originally termed “Strands of Informal Science Learning” (Fenichel & Schweingruber, 2010) and have been adopted by the project as its framework of science proficiency. The model was first developed to capture what it means to learn science in school settings; it was based on a four-strand model (Strands 1, 2, 3, 5) that was created for learning science in formal settings (National Research Council, 2007). Later, two strands (4 and 6: being interested in and excited by science, and identifying with the scientific enterprise) were added to emphasise the special value of informal STEM learning (National Research Council, 2009). The evolution of this framework shows that it integrates elements from both formal and informal science learning, and it helps us understand the relative areas of importance of these strands, as viewed by each science learning setting. For example, the strands of interest development and science identity are central to informal science settings and represent possible contributions to science learning in formal settings.

Figure 3. *The six strands of science proficiency, and their respective educational objectives for the design and implementation of informal STEM learning activities*



Understanding scientific content and knowledge

Generating, understanding, remembering, and using concepts, explanations, arguments, models, and facts related to science.

Engaging in scientific reasoning

Manipulating, testing, exploring, predicting, questioning, observing, analysing, and making sense of the natural and physical world.

Reflecting on science

Reflecting on science as a way of knowing, including the processes, concepts, and institutions of science. It also involves reflection on the learner's own process of understanding natural phenomena and the scientific explanations for them.

Being interested in and excited by science

Experiencing excitement, interest, and motivation to learn about phenomena in the natural and physical world.

Using the tools and language of science

Participation in scientific activities and learning practices with others, using scientifc language and tools.

Identifying with the scientifc enterprise

Coming to think of oneself as a science learner and developing an identity as someone who knows about, uses, and sometimes contributes to science.

In the project, these six science proficiency strands will serve as a broad framework for analysing and assessing the outcomes of informal STEM learning activities, as well as for providing insights into the design of such activities. Within this framework, two broad types of outcomes can be distinguished: cognitive outcomes (such as scientific content knowledge, scientific reasoning skills, and reflection on science and scientific processes) and affective outcomes (such as motivation, interest in science, and interest in pursuing a science-oriented career).

Strand 1, understanding scientific content and knowledge, refers to knowing, interpreting and using STEM related knowledge. It is not just about the facts of science, it is also about understanding the relation between different concepts and using these concepts in explanations and arguments. For example, after observing the social behaviour of ants at an exhibition (http://www.cittadellascienza.it/science-centre-en/bugsecompany/?lang=en), visitors might start hypothesising about the social behaviour of other species.

Strand 2, engaging in scientific reasoning, refers to skills that individuals need to reason about scientific information. This includes being able to design your own investigations and analyse and collect the data from these investigations. An example of scientific reasoning in an out-of-school setting is the exhibition presented in Marcus, Haden and Uttal (2018) where families are invited to stabilise a wobbly skyscraper. In this setting, visitors could explore the idea of diagonal bracing and structural integrity. While working on the engineering problem, family members could reason about engineering structures.

Strand 3, reflecting on science, in the context of STEM learning, is conceptualised as reflecting on scientific knowledge, processes, concepts and organisations, but also includes the way individuals reflect on their own scientific knowledge and reasoning. Outreach programmes have the potential to introduce people to the work of scientists and allow them to actively engage in scientific investigations and learn about knowledge construction in science.

Strand 4, being interested and excited by science, refers to the interest and excitement that STEM activities might elicit in individuals. Excitement, motivation and interest are associated with positive emotions that are not only pleasant but are also associated with engagement and deep learning (Carmona-Halty, Salanova, Llorens, & Schaufeli, 2018).

Strand 5, using the tools and the language of science, refers to (social) activities in which people use the tools and the language of science. For example, during out-of-school activities such as outreach programs, individuals can learn the language of science by learning what a hypothesis is. When engaged in science-related activities, children might learn to refine their terminology. Pre-schoolers who play around with objects that vary in density and a tank of water, might first talk about blocks that go to the bottom or swim in the water. In their interaction with others they might refine their language and start to use words like sinking and floating (Siry , Ziegler, & Max, 2012).

Strand 6, identifying with the scientific enterprise, refers to the extent to which individuals think about themselves in relation to science. This “science identity” can be expressed by using scientific innovations or scientific knowledge, but also by contributing to or liking to learn about science. An individual who identifies with science is more likely to take up science-related activities in their spare time or consider a career in a STEM-related field (Vincent-Ruz & Schunn, 2018).

Even though these six strands are interconnected, they can develop in a different order and at a different pace. Moreover, different informal STEM learning activities contribute differently to the development of one or more of these six strands . While watching belugas at an aquarium might spark a visitor's interest in these mammals (Strand 4), this experience does not necessarily affect the other strands. The simulated belugas activity at the Vancouver aquarium makes it possible for visitors to make changes in a virtual aquarium and observe the behaviour of the belugas (https://ivizlab.org/research/virutal-beluga-project-vancouver-aquarium/). The interactive character of this activity might spark interest (Strand 4), enable learners to participate in (simulated) science activities (Strand 2), acquire knowledge (Strand 1) about belugas (for instance, about the fact that they live in a world of sound) and use the tools and language of science (Strand 5) and through this process also identify themselves with the scientific enterprise (Strand 6).This example illustrates that the strands are intertwined, and that experiences and developments in one strand can support the development of other strands. By using the six-strand model as a framework for our assessment methodology, we will try to capture the full complexity of science proficiency. Studying how different activities contribute to science proficiency is a significant part of the project.

Former research has shown that informal STEM learning activities have the potential to elicit cognitive, affective, or both cognitive and affective outcomes, depending on the type, goal, and design of the activity (Bonnette, Crowley, & Schunn, 2019; Forest & Rayne, 2009; Whitesell, 2016). Both affective and cognitive outcomes affect the way people deal with scientific issues and information. For example, individuals with higher scientific reasoning skills might be less confused by the conflicting information that the media presents about the COVID-19 pandemic. Moreover, being able to identify oneself as a user of scientific information and reflecting on that information might help people distinguish between reliable and less reliable sources. The science identity of individuals changes over time: experiences of learners, activities they engage in, as well as the people they meet and the conversations they have, can influence their science identity. The six strands of science proficiency feed the assessment methodology, since measures will be defined to assess participants’ learning outcomes related to each of these strands. In this framework, the impact assessment approach of the project is expected to monitor individuals as they are moving towards science proficiency. Science proficiency, will also inform the development of the Digital toolbox (Work Package 3), as the stands’ content will contribute to the conceptual design of the app.

4 A connected science learning ecology: an individual journey

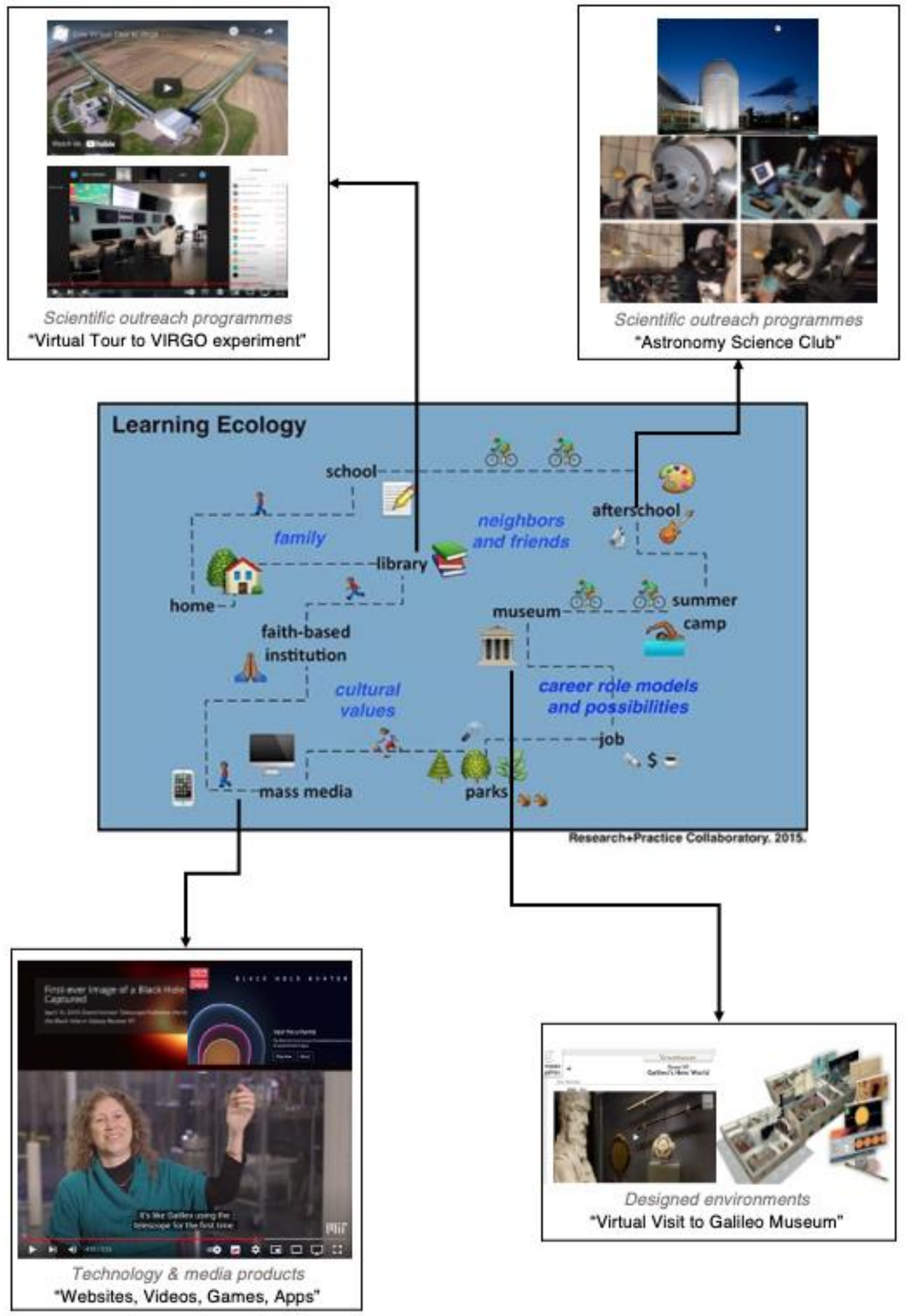
The aim of the project is to get a better understanding of how informal STEM learning activities contribute to the development of science proficiency and to support young people who pursue science proficiency in their journey, as well as to support out-of-school science organisations in playing a significant role in this journey. Characteristic of this journey is that (in addition to science activities in school) young people engage in different activities that can be categorised by the three contexts which were described in Section 3.3. To make this notion clearer, we provide an example of a possible journey or a learning pathway that can be described as a long-term out-of-school science learning experience cutting across the three learning contexts. The example also illustrates how key concepts of the project can come together to form a unique learning experience.

4.1 An example of an iSTEM learning experience

Title: Reveal the Past to Probe the Future: From Galileo to Gravitational Waves and Back

From the user's perspective, the learning pathway depicts the science learning experience as a timeline of scientific landmarks in the history of astronomy, from Galileo's first observations in the early 17th century to Einstein's formulation of the General Theory of Relativity in 1915, and almost one century later, to the Nobel prize-winning discovery of the Gravitational Waves by the LIGO experiment. During this multi-context journey, the user is involved in activities in non-formal and informal science education settings. The three learning contexts, settings and activities as shown in Figure 4 are described briefly in the following sections.

Figure 4. *Users' learning pathway focusing on key discoveries in the history of astronomy and cosmology (from 1610 to 2020). Through such extended learning experiences that are cutting across different learning contexts, learners can gain a deep understanding of the nature of science*



Activity: **Virtual Visit to Galileo Museum**

Setting: **Science Museum (non-formal education)**

Context: **Designed Environment**

The visitor to the Galileo Museum (https://www.museogalileo.it/it/) in Florence will be able to explore virtually the discoveries and the archives of Galileo Galilei through different access modes. Through the Surrounded by Science contextualised approach, the hypothesis, the instruments used, and the observations will be presented in a form of a storyline that will help the visitor to realise the scientific process. Furthermore, the visitor will be able to personalise the experience, e.g., by repeating the experiments of Galileo through the integration of innovative tools that are available today (i.e., the visitor will be able to study sunspots through real-time access to solar data through the SOHO space telescope (https://sohowww.nascom.nasa.gov/) and compare them with the images Galileo made in 1610).

Activity: **In the Footsteps of Galileo: Observing the Moons of Jupiter (Astronomy Science Club)**

Setting: **Research Facility (non-formal education)**

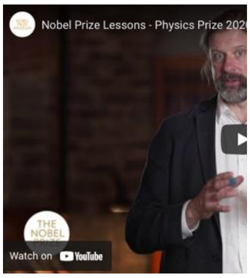
Context: **Scientific Outreach Programme**

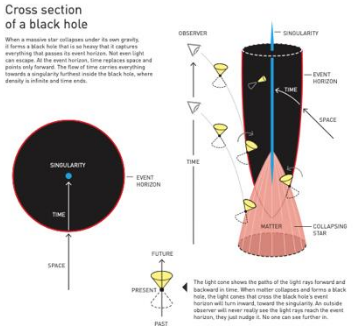
As part of Science Astronomy Club's activities, users conduct observations of Jupiter and Saturn by using a modern telescope. They also gather evidence of their observations (e.g., digitally processed images of Jupiter and Saturn) and then compare their observations with the ones made by Galileo. Users can also learn how to build their own telescope (hands-on activity with simple materials) and also use the Stellarium Astronomy Software (https://stellarium.org/) to perform observations of Jupiter and its moons and compare those observations with the ones made by Galileo.

Activity: **Watch Videos, Visit Websites**

Setting: **Digital Setting (informal education)**

Context: **Technology and Media Products**





When a massive star collapses under its own gravity, it forms a black hole that is so heavy that it captures everything that passes its event horizon. Not even light can escape. At the event horizon, time replaces space and points only forward. The flow of time carries everything towards a singularity furthest inside the black hole, where density is infinite and time ends.

The light cone shows the paths of the light rays forward and backward in time. When matter collapses and forms a black hole, the light cones that cross the black hole's event horizon will turn inward, toward the singularity. An outside observer will never really see the light rays reach the event horizon, they just nudge it. No one can see further in.

Figure 2. A black hole is formed.

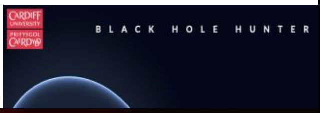
Following up on the previous activity, users can continue their journey by diving deeper into the "secrets" of the universe, for example, by learning about black holes, one of the most exotic phenomena in the universe. By watching videos and accessing digital content available at the Nobel Prize Foundation (https://www.nobelprize.org/the-nobel-prize-organisation/the-nobel-foundation/), users can learn about Roger Penrose, Nobel Laureate in Physics 2020, and his ingenious mathematical models to explore Albert Einstein's General Theory of Relativity that showed that black holes are a direct consequence of that theory. Albert Einstein originally predicted the existence of gravitational waves in 1916, on the basis of his theory of general relativity.

Activity: **The Discovery of Gravitational Waves: A Virtual Tour to the VIRGO Experiment'**

Setting: **Research Facility (non-formal education)**

Context: **Scientific Outreach Programme**

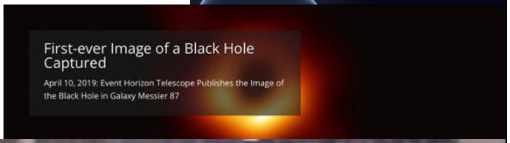
As part of VIRGO's outreach programme, users take part in a virtual visit to the experiment site, get introduced to basic concepts of general relativity and astrophysics, understand the basic structure of the VIRGO experiment and its optical scheme, perform a treasure hunt inside the interferometer experimental building, and discuss live with a scientist how the first-ever observation of gravitational waves (2015) happened and why it was awarded the Nobel Prize in Physics 2017. All these activities help to evaluate the importance of this discovery for improving our understanding of the universe.



Activity: **Watch Videos, Visit Websites, Play Games**

Setting: **Digital Setting (informal education)**

Context: **Technology and Media Products**



The users' science learning experience can continue in a digital setting through activities and interactions with technology and media products. For example, users can watch more videos related to the discovery of the gravitational waves that can help them understand the never-ending quest of scientists for understanding the fundamental laws that govern our universe, but also to make sense of the thread that connects the past, present, and future of science and technology and their role in society. Play-based activities are also recommended, especially for users of younger age, for maintaining their interest, excitement and motivation to learn about phenomena in the natural and physical world. An example of a game that is consistent with the proposed learning path is the "Black Hole Hunter", an online game designed by the Cardiff University Gravitational Physics Group. In this game, the users listen to gravitational wave detector data and determine whether or not they can hear the given gravitational wave signal in the sound file, or whether it is just noise.

4.2 From a pathway towards a research methodology

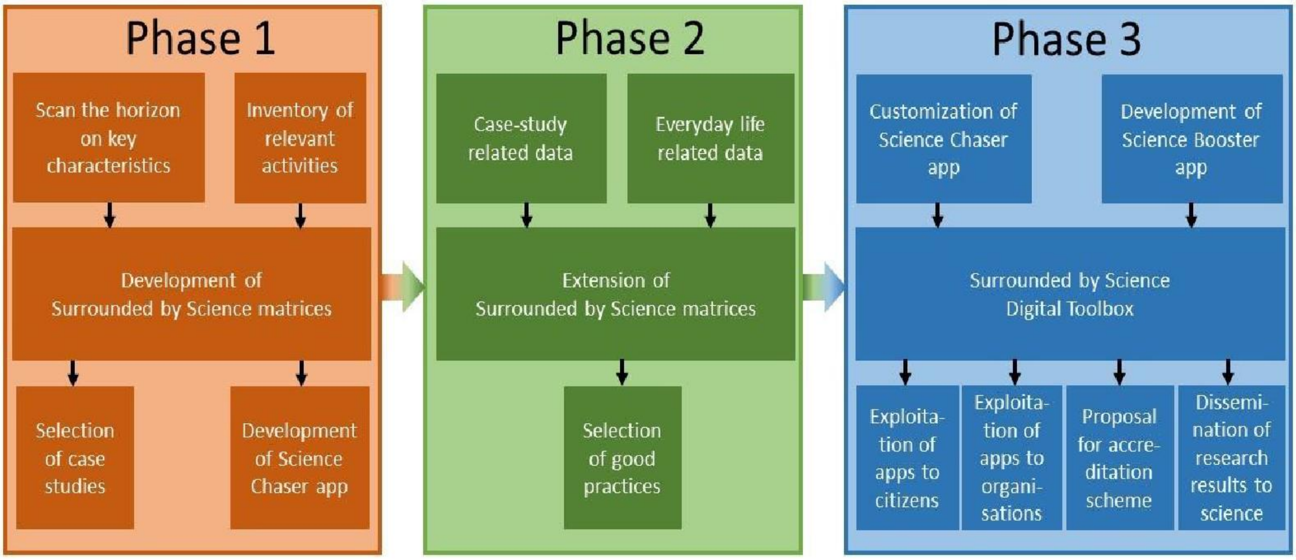
The above example presents a connected science learning ecology that shows possible connections between informal science activities. In the example, an individual can choose to engage in specific science activities leading to his or her individual learning pathway that can contribute to the development of his or her science proficiency. This process can be supported by providing engaging science activities that contribute to the science proficiency strands and make connections between the activities stronger. To be able to do this, we need to zoom into different types of activities, their key design features, success criteria etc. By studying these activities, in this way, we can provide support and scaffolds that are tailored to the needs of a user in a specific learning context. This process results in two research foci, one focusing on the science activities (i.e., investigating the nature of science activities and their effects and exploring their key features) and one focusing on the connections (i.e., creating effective links between the science activities). These two foci are combined into the research methodology, which is discussed in the next chapter.

5 Research methodology

The project aims at developing a framework that can help individuals to create a learning path based on circumstances, goals, interests, personal preferences, and career aspirations. The framework can also help organisations and institutions evaluate the impact of the activities they provide and modify them based on institutional goals, resources, priorities, opportunities, and other circumstances.

To reach the goals, the project is divided into three phases. See Figure 5 for a graphical overview of these phases and their corresponding activities. Phase 1 focuses mainly on the nature of out-of-school activities. It consists of tasks that will be performed within WP2 (the research that is done to get insight into this nature) and WP3 (the development of the part of the Science Chaser in order to be able to perform the research in Phase 2). Phase 2 focuses mainly on the effects of out-of-school activities. The tasks within this phase are part of WP4 (implementation of the research that must provide us with the insight into the effects) and WP5 (focusing on the design and implementation of the impact assessment and selecting good practices). Phase 3 focuses on the self-assessment of out-of-school science activities and suggestions for improvement. Tasks within this phase are part of WP3 (development of the digital toolbox consisting of the Science Chaser and Science Booster), WP6 (setting up a roadmap for an accreditation scheme and a plan for exploitation) and WP7 (dissemination activities).

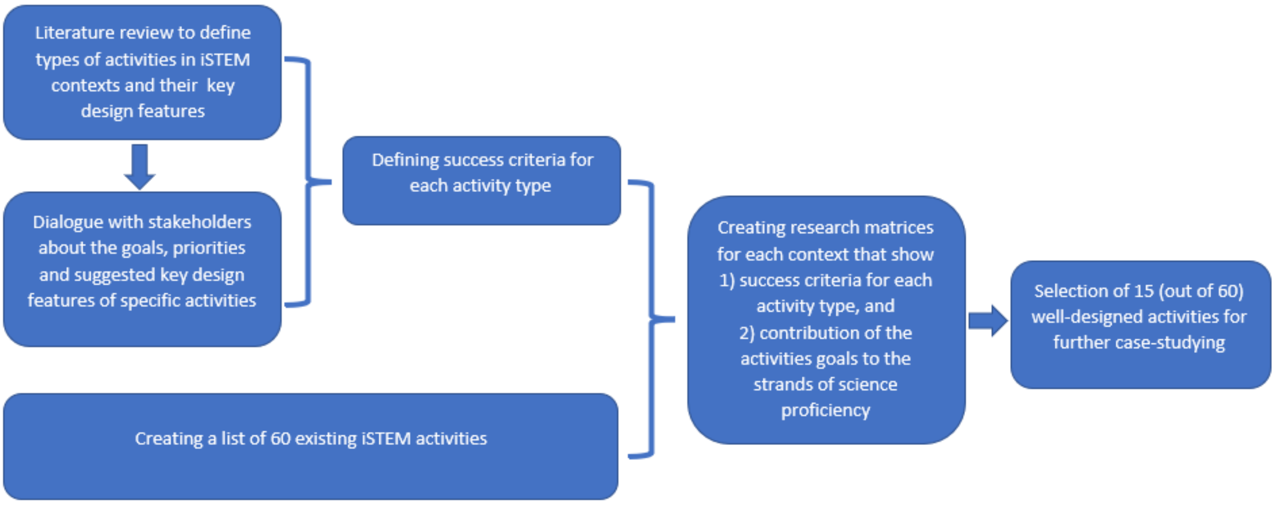
Figure 5. *The three research phases and corresponding activities*



5.1 Phase 1: The nature of iSTEM learning activities

The aim of Phase 1 is to get an overview of which types of iSTEM learning activities exist, and which criteria must be met for these activity types to be optimally designed. This phase gives insight into the nature of the available types of activities. The phase includes several tasks that are interconnected. Figure 6 presents how the output of each task belonging to Work Package 2 serves as the input for other tasks.

Figure 6. *Tasks of WP2 in Phase 1 with the expected results*



5.1.1 Scanning the horizon

The first step is to create an understanding of what types of iSTEM learning activities exist now and what their key design features are. Towards this end, a wide scan of existing iSTEM activities will be executed using available repositories (e.g., created during the SySTEM 2020 project), and using the information provided by the museum partners and national coordinators in each country that participates in the consortium. At least 60 iSTEM activities representing three contexts (outreach programmes, designed environments and technology/media products) will be identified. At the same time, a literature review will be conducted, resulting in a list of key design features (including didactical, multimedia and other approaches) for activities in all three contexts. This list will be one of the inputs for establishing a productive dialogue with stakeholders.

This productive dialogue consists of interviews with activity-providers and other stakeholders. They will be conducted with the aim to verify the key design features originated from the literature and to learn what characteristics of this type of activities they find important for success, as well as to reveal the connection of the activity with the science proficiency strands. Different activities may contribute to the development of science proficiency differently, depending on the goals identified by the activity providers and their target audiences. It is important to mention that not all activities are expected to contribute to all six strands. Especially shorter activities may have a focus on one or two strands, while longer and more complex activities or programmes (sets of coherent activities belonging together), may connect to all strands. However, even for this type of activity a possible focus or more obvious goals need to be identified.

To get a better understanding of what aspects of the activities make an impact on participants' science proficiency, a framework suggested by the National Research Council (2015) will be used. This framework can help to identify and develop effective out-of-school STEM programmes. Based on this framework questions for the interviews with stakeholders about engaging visitors, responding to their needs and presenting an individual activity as part of a bigger picture of iSTEM learning can be formulated. These interviews will allow us to understand the activities, the priorities and expectations of stakeholders in the area of informal STEM learning. The interviews will take a structured format and focus on getting information about important aspects (the questions below the presented aspects are examples):

- Connection to science proficiency:
    - What are the parts of the activity and its goal?

  - Based on the indicated goal, to which strand(s) of science proficiency does the activity/programme contribute and in which way?
- Key design features:
  - What characteristics did you consider important while designing the activity/activities in the programme?
  - Why do you find them important?
- Impact evaluation:
  - How do you evaluate the effectiveness of the activity/programme?
  - How does the activity engage young people intellectually, academically, socially and emotionally?
  - How does the activity/programme respond to young people's interests, experiences and cultural practices?
- Place of the activity in a bigger picture:
  - Does the activity/programme relate to STEM learning in formal settings? If yes, how?
  - Do you know any other iSTEM learning activities that participants of this activity can take as preparation and/or as follow-up?

The result of such interviews, along with studying the available information about the activities, will be an extensive table about each activity/programme. This table will help the project team to move to the next step – defining the success criteria for iSTEM learning activities.

During the interviews conducted with stakeholders, their opinions on the key features of their activities will be collected, as well as their comments about the key design features, as proposed by the literature review. Matching these two visions should support the list of suggested success criteria from the research and experience points of view. These success criteria will include design, instructional, technological and other aspects relevant to a particular activity. There will be a shared set of characteristics constructed for all activities in the same contexts, but there will be some differences between three contexts.

5.1.2 Developing the research matrices and selecting the case studies

A separate research matrix will be created for each of the learning contexts and it will include two types of information based on the results of the previous steps. First, the research matrix will present the key design features for a particular activity type and identify what turns these features into success criteria. Second, the research matrix will connect the goals of a specific activity type with expected contributions to the development of science proficiency. In this way, the project team aims at connecting the activities through their key design features and goals to the science proficiency, which will be used not only for the next step – selecting the case studies – but also for developing the recommendations in Phase 3 (see Section 5.3).

The final step in this phase is selecting case studies. Sixty activities identified in previous steps will be evaluated using the relevant success criteria with the aim of choosing 15 case studies (five for each context) for the detailed analysis and research. The five selected activities for each context will not only follow the identified success criteria, but will also give a practical opportunity for in-depth research (i.e., they are still running, there is or is possible to have an agreement of collaboration with the activity-provider, etc.). These activities will then be studied further and deeper in Phase 2 using different research perspectives to get insights about what makes them effective and what contribution they make to the development of science proficiency.

The results of these tasks in Phase 1 will be presented in deliverables D2.2 and D2.3.

5.1.3 Developing the science chaser app

Based on the insight about the nature of science activities, the science chaser app will be developed. The goal of this app is to monitor users' science-related activities (e.g., visits to science centres, participation in after-school science clubs and projects, watching a scientific documentary, performing an experiment at home, visiting a web site, reading a scientific article or a book) and to provide recommendations for related future activities. In addition to the content-related output coming from WP2, the development of the app will also be based on integrating the technical possibilities with the requirements coming from different work packages, e.g., Impact assessment (WP5) and Research implementation (WP4). Ethical considerations (such as privacy rules, forms of consent, etc.) will also be taken into account in the development process. The app will be used in the research conducted in Phase 2, which is presented next.

5.2 Phase 2: The effects of iSTEM learning activities

The aim of Phase 2 is to better understand how young people use iSTEM learning activities and how these activities affect their learning and motivation. The research in this phase will partly be conducted with the help of the science chaser app.

Using the science chaser app will allow us to conduct an in-depth analysis of the case studies and collect specific data to get specific feedback on selected science activities and to measure the impact on young people's learning paths to science proficiency.

To be successful and effective, activities should: a) attract and keep the attention of the visitors, b) lead to the intended interaction or behaviour, and c) lead to the intended learning outcomes. To get insight into these elements, the 15 case studies selected in Phase 1 will be assessed in three ways. Inspired by the “grain-size” continuum of measurements of engagement in science learning (Sinatra, Heddy, & Lombardi, 2014), these case studies will be assessed from a context-oriented perspective, a person-in-context perspective, and a person-oriented perspective, respectively.

(a) Context-oriented perspective

The context-oriented perspective focuses on capturing the characteristics of the context in which science activities take place. To get an understanding of those characteristics that trigger attention and interaction, the behaviour of visitors will be observed. The number of visitors will be counted, and more specific counts will inform us about the specific activities that attract visitors, as well as the duration of their interaction with these elements. For scientific outreach programmes and designed environments (e.g., a museum exhibition), visitors will be observed and/or tracked. For technology and media products (e.g., a website), tracking will be used.

(b) Person-in-context perspective

The person-in-context perspective strives to give insight into the interaction and experiences of the individual visitor with a specific activity. Based on measurements of the duration of a visit and the elements that have (and have not) been visited, visitors will receive a small set of questions. These questions will include self-reports about the visitors' experiences, their appreciation and accessibility of the activity, their perceived learning, and their motivation to participate in other science activities. The questions will be informed by the strands of science proficiency.

(c) Person-oriented perspective

To get a more detailed understanding of the effects that out-of-school science activities have on individual visitors, an in-depth study will be performed. Selected activities will be paired with a group of visitors that matches the intended audience of the activities. The participants will be recruited at schools, after-school programmes, or community centres to which the consortium has access. Assessment will focus on the six strands of science proficiency. Tests and questionnaires will be completed before and after engagement with an activity to assess outcomes related to the strands. For example, the first strand, which focuses on understanding scientific content and knowledge, will be measured by a knowledge test. To ensure that the assessment matches the content and the context of the activity, different tests will be developed. All tests will assess the same types of knowledge (factual, conceptual, procedural, etc.) for each of the activities. In this way, the tests will be comparable across different activities and will provide the opportunity to identify to what extent a certain activity produces a specific outcome.

(d) Everyday-life perspective

In addition to the three perspectives which use the case studies as starting points, another perspective will be taken that focusses on science activities in everyday life as a starting point. Individual journeys towards science proficiency will be registered in the science chaser app. Visitors and participants in the case-study related assessments will be invited to install the science chaser app on their mobile phone. In case of younger participants, the app can be installed on the phone of their parents or guardians, while the information is collected about the children's activities. The app will be used to collect user data outside and independent of specific organised activities.

While the young people participate in or perform specific science-related activities, the app will monitor their learning paths. It will continually collect data about their actions in the app, making inferences about their goals and preferences, in order to provide suggestions for further learning.

Users are, on a regular basis, asked to self-report their science activities during the week, such as watching a documentary, reading a science magazine, or visiting a science-related website. Based on these reports, we will get insights into what kind of activities specific groups of users do and do not engage in and whether different profiles of users can be distinguished. These profiles will be based on preferences, such as preferences regarding learning contexts and specific activities, as well as the extent to which these activities are used.

This embedded assessment scheme provides an innovative way to collect information about participants' learning states and paths without asking them to stop and take a test or fill in a questionnaire. Embedded assessment is any assessment that is given to learners as an integral part of their experience. Embedded assessments can be integrated into interactive environments (e.g., simulations, games, and intelligent tutors) at different levels. These levels of integration range from direct assessment activities that may or may not be part of a coherent scenario to completely transparent, unobtrusive sets of actions or "stealth" assessments (Shute, 2011). Embedded assessment can be built on the concept of conversational agents that have been developed to help users learn in computer learning environments with collaborative reasoning and problem solving (Graesser, Forsysth, & Folts, 2017). By deploying game-based techniques, the science chaser will engage participants in exploration journeys in science related to their interests and inform the project team about such journeys.

A general overview of the research perspectives and intended assessment forms is presented in Table 3. The classification of assessment forms for informal STEM learning is based on their directness and obtrusiveness adopted after Fu, Kannan and Shavelson (2019).

Outcomes of this phase are input for Phase 3, which will be presented next.

Table 3. *Overview of the target groups and assessment forms*

Perspective	**Group**	**Assessment**	**Science Chaser App usage**
Context-oriented	The biggest group (for example, 100 per time): all visitors of an exhibition on a particular day, all users of a website, all participants of a particular outreach programme	Direct and unobtrusive forms, such as observations, app logs, website logs, etc.	partly
Person-in-context	A subgroup of the previous group (for example, 40 per time): a focused group of visitors, users, participants	More direct and less obtrusive forms, e.g., an embedded game; OR less direct and more obtrusive forms, e.g., surveys, questionnaires and interviews.	partly
Person-oriented	A smaller group recruited directly for the data collection about a particular activity (for example, a class of 25 students)	More direct and more obtrusive forms – pre- and post-tests assessing different stands of the Science Proficiency model depending on the activity.	partly
Everyday life (not for case studies)	Active app users recruited after participation in one of the activities	Less direct and more obtrusive forms, e.g., self-report or a short survey.	yes

5.3 Phase 3: Self-assessment of iSTEM learning activities and suggestions for improvement

The aim of Phase 3 is to support organisations that are involved in science activities outside the classroom in determining the quality of their activities and in improving these activities. This support will be provided by developing the science booster app that consists of a self-assessment instrument and an advice tool. Organisations can use the self-assessment instrument to evaluate the design and effectiveness of their activities based on the expanded matrix created in Phase 2. This self-assessment can make providers of iSTEM activities more aware of their goals, whether they reach these goals with their current activities, and whether they want to make improvements (e.g., not only aim for interest and excitement, but also for scientific reasoning). By answering questions concerning their activities, organisations receive scores for different categories, which helps them to place their current position in terms of contribution to the science proficiency strands.

As a next step, the organisations will automatically get customised feedback and suggestions for improvement. This feedback is tailored advice, adapted to the specific characteristics and objectives of the activity and organisation. The advice will be based on the Surrounded by Science matrix that presents success criteria for key design features of different activities and their contribution to science proficiency strands. Furthermore, when possible, organisations will receive suggestions that can help them make their activities more effective (e.g., a suggestion to add a preparatory activity to a museum visit, or suggestions for a tool in which they can register the data of a field trip). Organisations can also decide to use the science chaser app for this purpose, if they desire.

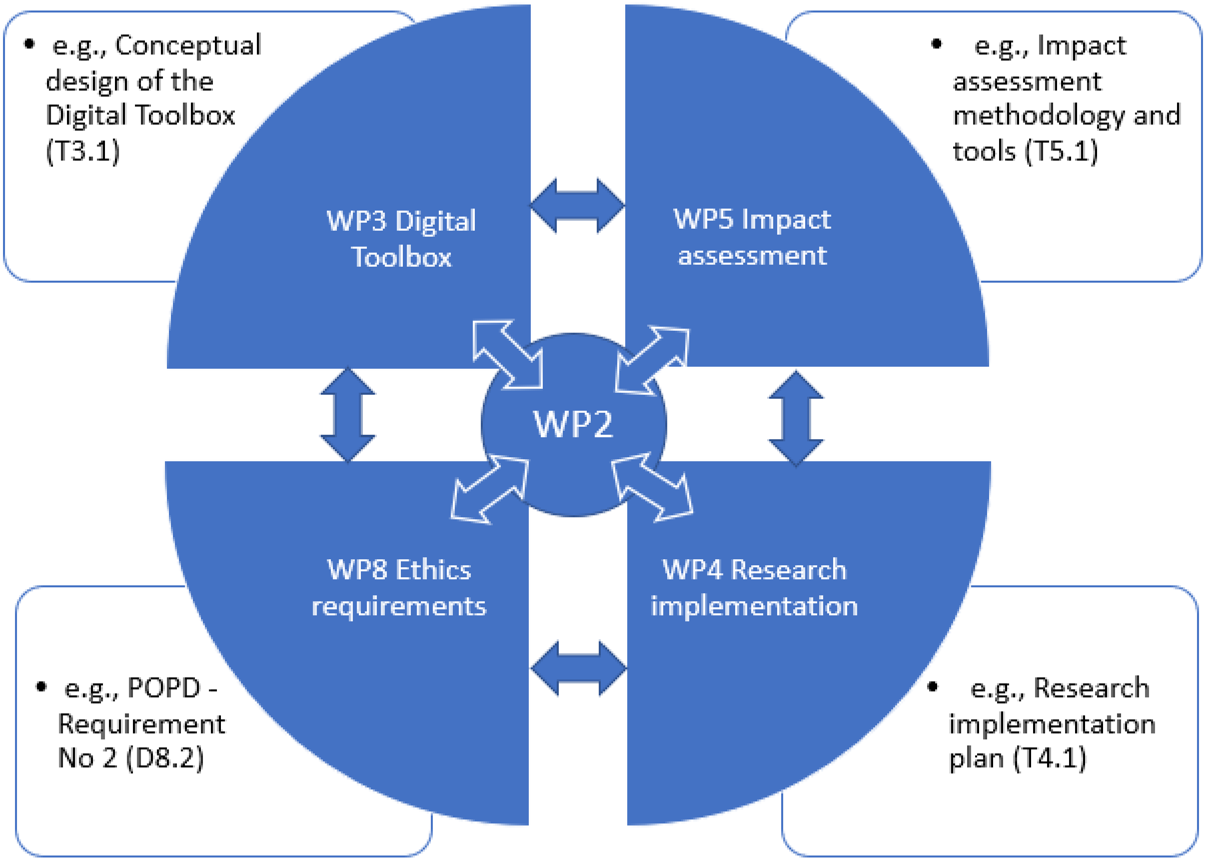
The final step of the project is the dissemination of its findings and insights to practice, science, and policy. This effort will be documented analytically and systematically in the roadmap for designing effective iSTEM activities that will be one of the main deliverables of the project. This document will be the first step in a journey of educational reform that might take many years. This document will also include a proposal for accreditation of iSTEM activities so that they can be more easily and effectively found and connected to formal learning settings. In this way, both formal and informal learning settings will work together to reach the same goal – develop young people's science proficiency. The project team shares the understanding that the achievement of high-quality science education requires combined, continued and coordinated support of all involved actors: researchers, policy makers and curriculum developers, as well as the staff members of out-of-school organisations, principals, science teachers' educators, teachers, students, and parents.

6 Conclusion

This deliverable presented the research methodology of the Surrounded by Science project. First, the need to bridge STEM learning in formal and informal settings, as well as the project's research question were introduced. Next (in Chapter 3), the core concepts used in the Surrounded by Science methodology were presented, including the different contexts in which informal science learning can take place and the model of science proficiency. The six strands of this model will guide the impact assessment of the informal STEM learning activities. Chapter 4 showed our view and ambition on the project and provided an example of an iSTEM learning pathway including different activities and contexts. The following chapter (Chapter 5) described the project's research methodology, including possible assessment forms and tools, with special attention given to the tasks of Work Package 2.

Work Package 2 is one of the first packages to start, as it lays the road for and contributes to other work packages. The main goal of Work Package 2 is to provide a methodological approach for other packages. In particular, it informs the development of the Digital Toolbox (WP3) and the impact assessment (WP5) by identifying the research perspectives for assessing the role of iSTEM learning activities in forming science proficiency. It shapes the research implementation (WP4) by providing the general approach to research within the framework of the project. It also influences ethics (WP8) by shaping requirements for assessment procedures and participants groups. An overview of these contributions is presented in Figure 7.

Figure 7. *An overview of WP2 contribution to other WPs*



7 References

Bevan, B. (2016). STEM learning ecologies: Relevant, responsive, and connected. *Connected Science Learning*, *1*. Retrieved from https://www.nsta.org/connected-science-learning/connected-science-learning-march-2016/stem-learning-ecologies

Bonnette, R. N., Crowley, K., & Schunn, C. D. (2019). Falling in love and staying in love with science: Ongoing informal science experiences support fascination for all children. *International Journal of Science Education*, *41*, 1626-1643. doi: 10.1080/09500693.2019.1623431

Brown, A., Kapros, E., & Roche, J. (2021). SySTEM 2020: Conceptual Framework for Science Learning Outside the Classroom [White paper].

Carmona–Halty, M., Salanova, M., Llorens, S., & Schaufeli, W. B. (2019). How psychological capital mediates between study-related positive emotions and academic performance. *Journal of Happiness Studies*, *20*, 605-617. doi: 10.1007/s10902-018-9963-5

Dierking, L., Falk, J., Shaby, N., & Staus, N. (2021). Thriving STEM learning ecosystems – for all? *Connected Science Learning, 3*. Retrieved from https://www.nsta.org/connected-science-learning/connected-science-learning-november-december-2021/thriving-stem-learning

Eshach, H. (2007). Bridging in-school and out-of-school learning: Formal, non-formal, and informal education. *Journal of Science Education and Technology*, *16*, 171-190. doi:10.1007/s10956-006-9027-1

Falk, J. H., & Dierking, L. D. (1998). Free-choice learning: An alternative term to informal learning? *Informal Learning Environments Research Newsletter*. May/June, Washington, DC, American Educational Research Association.

Falk, J., & Dierking, L. (2010). The 95 percent solution. *American Scientist*, *98*, 486-493.

Falk, J. H., & Dierking, L. D. (2019). Reimagining public science education: The role of lifelong free-choice learning. *Disciplinary and Interdisciplinary Science Education Research*, 1, 1-8. doi: 10.1186/s43031-019-0013-x

Fallik, O., Rosenfeld, S., & Eylon, B. (2013). School and out-of-school science: A model for bridging the gap. *Studies in Science Education*, *49*, 69-91. doi: 10.1080/03057267.2013.822166

Fenichel, M., & Schweingruber, H. A. (2010). Learning science in informal environments: People, places, and pursuits. National Academies Press.

Forest, K., & Rayne, S. (2009). Thinking outside the classroom: Integrating field trips into a first-year undergraduate chemistry curriculum. *Journal of Chemical Education*, *86*, 1290-1294. doi: 10.1021/ed086p1290

Fu, A. C., Kannan, A., & Shavelson, R. J. (2019). Direct and unobtrusive measures of informal STEM education outcomes. In A. C. Fu, A. Kannan, & R. J. Shavelson (Eds.), *Evaluation in informal science, technology, engineering, and mathematics education*. *New Directions for Evaluation*, *161*, 35-57. doi: 10.1002/ev.20348

Graesser, A., Forsyth, C., & Foltz, P. (2017), Assessing conversation quality, reasoning, and problem solving with computer agents. In B. Csapó & J. Funke (Eds.), *The nature of problem solving: Using research to inspire 21st century learning.* Paris: OECD Publishing. doi:10.1787/9789264273955-17-en.

Hofstein, A., & Rosenfeld, S. (1996). Bridging the gap between formal and informal science Learning. *Studies in Science Education*, *28*, 87-112.

Marcus, M., Haden, C. A., & Uttal, D. H. (2018). Promoting children's learning and transfer across informal science, technology, engineering, and mathematics learning experiences. J*ournal of Experimental Child Psychology*, 175, 80-95. doi:10.1016/j.jecp.2018.06.003

Mejias, S., Thompson, N., Sedas, R. M., Rosin, M., Soep, E., Peppler, K., & Bevan, B. (2021). The trouble with STEAM and why we use it anyway. *Science Education*, 105(2), 209-231. doi: 10.1002/sce.21605

National Research Council. (2007). *Taking science to school: Learning and teaching science in grades K-8. Committee on Science Learning, K-8*. R.A. Duschl, H.A. Schweingruber, and A.W. Shouse (Eds.). Washington, DC: The National Academies Press.

National Research Council. (2009). *Learning science in informal environments: People, places and pursuits*. Washington, DC: National Academies Press.

National Research Council. (2010). *Surrounded by science: Learning science in informal environments*. Washington, DC: National Academies Press.

National Research Council. (2015). *Identifying and supporting productive STEM programs in out-of-school settings*. Washington, DC: National Academies Press.

Simon, A., Geldreich, K., & Hubwieser, P. (2019). How to transform programming processes in scratch to graphical visualizations. *Proceedings of the 14th Workshop in Primary and Secondary Computing Education* (pp. 1-9).

Sinatra, G. M., Heddy, B. C., & Lombardi, D. (2014). The challenge of defining and measuring student engagement in science. *Educational Psychologist*, *50*, 1-13. doi: 10.1080/00461520.2014.1002924

Siry, C., Ziegler, G., & Max, C. (2012). "Doing science" through discourse-in-interaction: Young children's science investigations at the early childhood level. *Science Education*, *96*, 311-336. doi: 10.1002/sce.20481

Smyrnaiou, Z., Georgakopoulou, E., Sotiriou, M., & Sotiriou, S. (2017). The Learning Science through Theatre Initiative in the Context of Responsible Research and Innovation. *Systemics, Cybernetics and Informatics*, *15*(5), 14-22.

Sotiriou, S., Bybee, R., & Bogner, F. X. (2017). PATHWAYS – A case of large-scale implementation of evidence-based practice in scientific inquiry-based science education. *International Journal of Higher Education*, *6,* 8-17. doi:10.5430/ijhe.v6n2p8

Shute, V. J. (2011). Stealth assessment in computer-based games to support learning. *Computer games and instruction, 55*, 503-524.

Tisza, G., Papavlasopoulou, S., Christidou, D., Iivari, N., Kinnula, M., & Voulgari, I. (2020). Patterns in informal and non-formal science learning activities for children–A Europe-wide survey study. *International Journal of Child-Computer Interaction*, 25, 100184. doi: 10.1016/j.ijcci.2020.100184

Vincent-Ruz, P., & Schunn, C. D. (2018). The nature of science identity and its role as the driver of student choices. *International journal of STEM education, 5*, 1-12. doi: 10.1186/s40594-018-0140-5

Whitesell, E. R. (2016). A day at the museum: The impact of field trips on middle school science achievement. *Journal of Research in Science Teaching*, *53*, 1036-1054. doi: 10.1002/tea.21322

Zolotonosa, M., & Hurley, M. (2021). Reshaping science learning: Findings and recommendations from SySTEM 2020. Ireland: Trinity College Dublin. doi: 10.5281/zenodo.4898865