EUROSCITIZEN COST ACTION - WORKING GROUP INFORMAL EDUCATORS (WG3)

GUIDE

Developing non-formal learning activities focused on increasing evolutionary knowledge and scientific literacy

This article/publication is based upon work from COST Action < CA17127 Building on scientific literacy in Evolution towards scientifically responsible Europeans >, supported by COST (European Cooperation in Science and Technology).
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Abstract
Non-formal learning activities have an important role in continuous education of the general audience, and thus provide an essential element in increasing evolutionary knowledge and scientific literacy for European citizens, beyond the formal schooling. This guide brings together explanations of how non-formal learning can be designed, with special emphasis on evaluating the activities. The guide describes common activity types and examples encountered in our scoping conducted via surveys, personal contacts, and literature and internet search. It also provides reflection points for practitioners (activity designers, educators, science communicators) to embed evaluation as a form of engaging activity participants, as well as a tool to assess the impact and improve practice.

Keywords
non-formal evolution education, scientific literacy, workshops, citizen science projects, arts and science, educational trails, info boards, games, MOOCs, public outreach, non-formal education evaluation

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Contents

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Introduction

The EU COST Action EuroScitizen is dedicated to investigating the approaches used to improve public scientific literacy in evolution by bringing evolutionary biologists, educational researchers, formal and non-formal educators, and science communicators (including traditional and digital media professionals) in collaborative discourse. One specific goal of the Action is to explore learning opportunities in evolution across Europe in non-formal contexts.

Working group 3 (WG3) of the EuroScitizen COST Action is focused on identifying and examining the best practices in 'non-formal' educational programmes that include science exhibitions, workshops, art installations, games, nature walks etc. Furthermore, it is focused on amplifying the effective messages that increase the understanding of evolution and scientific literacy in general across Europe. Despite the huge potential that natural history museums, botanical gardens, science centres, and all other institutions that are focused on non-formal education have in promoting lifelong learning, their contribution to improving evolution understanding in Europe has received little attention (Adnađević et al., 2020). In the US, studies have shown that learning evolution in a museum setting can be highly effective and that even one visit to an evolution exhibition can enhance visitors' knowledge and understanding of evolution while additionally helping resolve many pre-existing misconceptions (Spiegel et al., 2012).

The aim of this guide is to present a theoretical and practical overview of evolutionary-themed non-formal education activities, especially focusing on examples from Europe. The landscape of activities is very diverse; therefore, we present guidelines for non-formal educators that will contribute to building up the public's scientific literacy in evolution.

Statement of purpose (scope and goals)

This guide presents a non-exhaustive overview of some of the types of evolution-themed non-formal education. We provide a set of non-formal activities we have identified in the period between 2019 and 2021 in Europe, through personal contacts, published articles and freely accessible online materials.

Besides mapping such activities in Europe, the aim of this guide is to provide a theoretical background, and to suggest some general guidelines on developing and presenting various evolution-themed non-formal education activities. We hope this guide will serve as a manual and 'how-to' document that will enable and empower researchers, science communicators, museum curators, and non-formal educators to better understand and apply the best practices in communicating about evolution and conveying the basics of scientific literacy to the general public. Our suggestions are based not only on our experience as non-formal educators, but also on the analysis of activities that we have identified as good examples in addressing evolution and scientific literacy.

Irrespective of the type of activity, be it ‘entertaining’ activities, ‘hands-on’ activities, ‘unsupervised self-paced’ activities, or science outreach events, we hope this guide will provide useful insights for both novice and experienced educators seeking effective ways to improve the impact of their non-formal activities.

Since our aim is to improve the impact of these activities, the guide would not be complete without suggestions on how to assess the impact of such activities. We therefore, provide a basis for reflection for those who want to understand why, how and when assessment could be implemented.

Background

In a fast-changing and complex world, it is important for people to develop competencies (knowledge, skills, and attitudes) to manage various challenges and take advantage of new opportunities. As a result of the certification systems, many societies are mainly focused on formal learning in educational institutions. Therefore, the potential opportunities offered by non-formal education remain unrecognised. Additionally, peoples’ motivation and confidence to continue learning throughout life is still not well established, incentivised, or promoted (UNESCO Institute for Lifelong Learning, 2012).

To include the full spectrum of learning opportunities, more focus should be drawn on non-formal and informal science education. Such science education projects and activities are abundant and are intended to engage different audiences. In this field, diverse outcomes are the norm, and learning is often the result of an amalgamation of experiences (formal, informal, and non-formal) (Lloyd et al., 2012; Task Force on Professional Standards, Standing Professional Committee on Education [EdCom], 2005). To best design experiences that have favourable outcomes, the focus therefore needs to be on understanding how the experience of participating in, or engaging with, the science-themed activity contributes to fostering, reinforcing, and sustaining interest in science, understanding of scientific concepts, and scientific literacy in general (Allen et al., 2008).

Before designing any non-formal learning activity, the emphasis should be on identifying the intended learning goals and objectives, and the target audience. Based on this information, content producers should then be able to design and choose the appropriate format and type of the non-formal activity that will both engage the targeted audiences, and achieve the intended goals and objectives. Also, they should focus on the specific impact categories in advance, to be able to assess and communicate the potential impact of the project to stakeholders (Allen et al., 2008).

Considering the wide range of activities that come under the umbrella of non-formal education, as well as the diversity of target audiences, there is no one-size-fits-all approach to designing a 'good' non-formal learning activity (EdCom, 2005). This guide will share principles of good practice and provide guidelines for different actors involved in the making of various types and formats of the activities in the field of evolution-themed non-formal learning. Additionally, it will propose general recommendations and principles for implementing each type of activity. Finally, it will provide some broad ideas about assessing non-formal learning activities.

Responsible research and innovation

Responsible Research and Innovation (RRI) is a conceptual framework and toolbox supported by the European Commission to promote responsible conduct in research and innovation (Burget et al., 2017). RRI's goal is to intermingle crucial ethical features of research with wider societal interests and ethical values. Ethics, gender equity, governance, open access, public engagement and science education are the pillars (i.e. keys) of this vision. As an outcome, science, culture, politics and ethics are connected to ensure a democratic vision of science (Stilgoe et al., 2013). Accordingly, all the actors of the society (scientific community, educators, communicators, citizens, policymakers, etc.) should take the opportunity/responsibility to build upon the present scientific culture and knowledge. It is worth stressing that such a view is recognized as an essential approach to address the EU Grand Societal Challenges (NCP Wallonia, n.d.) and the UN's Sustainable Development Goals (UN Department of Economic and Social Affairs, n.d.).

The structure and aims of EuroScitizen COST Action reinforce the RRI vision by leveraging the strengths of diverse stakeholders (evolutionary biologists, education researchers, educators, museum professionals and the media) and by building scientific literacy (i.e. the ability to critically evaluate, apply and understand scientific knowledge and how it is produced). EuroScitizen, in fact, is set based on the RRI framework, as stated in the Memorandum of Understanding: "*The Action will contribute to a culture of responsible, research and innovation (RRI) [by] promoting a culture of RRI amongst [the Action's] researchers, by enabling them to collaborate with other stakeholders involved in the Action and ensuring the successful dissemination to society*" (Aanen et al., 2018).

According to the RRI vision, non-formal education plays a crucial role in generating a knowledge-based society and in building up scientific citizenship, i.e. allowing citizens to make informed decisions about science and based on science. Accordingly, locations where non-formal education is practised, such as museums and science centres, should act as a modern agora, where science and society can meet and experiment with tools that engage people in challenging conversations. Such a metaphor of 'the square' represents the mission of cultural institutions to act as elite forums to foster and promote communication, actively engaging the various actors of modern science (Beltrame et al., 2019). In this framework, scientific literacy in evolution is a good model to explore and practise the RRI mindset, as well as to test the various tools available in the literature (Home Page - RRI Tools, n.d.) to invite the different actors to explore such a fundamental biological theory.

Concepts and definitions

Scientific literacy

Educational organisations within the EU, as well as in other parts of the world, have defined scientific literacy very broadly. They were primarily focusing on the acquisition and implementation of scientific skills and knowledge in issues connected to active citizenship and societal needs. Accordingly, we have defined **scientific literacy as "*the ability to understand, evaluate and apply scientific content in our daily realities and to understand how it is generated*"** – because we believe it is crucial for citizens to make informed decisions about important societal issues, a skill which is augmented by their capacity to understand science (Aanen et al., 2018). Scientific literacy is also a primary goal for science education which falls within the objectives of the 21st century vision for science for society within the broader European agenda (European Commission, Directorate-General for Research and Innovation, 2015).

Similarly, the National Research Council of USA, has described **scientific literacy as "*the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity*"** (National Research Council [NRC], 1996a). The Organisation for Economic Cooperation and Development (OECD) annually assesses scientific literacy through the Programme for International Student Assessment (PISA). Their definition reads **"*the ability of a reflective citizen to engage with science-related issues, and with the ideas of science. A scientifically literate person is willing to engage in reasoned discourse about science and technology, which requires the competencies to explain phenomena scientifically, evaluate and design scientific enquiry, and interpret data and evidence scientifically.*"** (OECD, 2019).

The EU, considers scientific literacy to be a key competence, and defines it as **"*the ability and willingness to explain the natural world by making use of the body of knowledge and methodology employed, including observation and experimentation, in order to identify questions and to draw evidence-based conclusions*"** (Council of the European Union, 2018). We can therefore conclude that scientific literacy is one of the competences that include a set of specific knowledge, skills and attitudes, contributing to the toolkit of a scientifically literate citizen.

Non-formal education

In the 'Exploratory study of evolution-themed, non-formal education in Europe' (Adnađević et al., 2020) we adopted the definitions for formal, non-formal, and informal science learning as presented by the National Centre for Vocational Education Research of Australia (Naidu et al., 2013). Their universality, and inclusiveness with regard to subjects, levels, and contexts make them functional for a variety of ages, countries, activities, abilities, and topics. Non-formal science learning is therefore **"*any organised and sustained educational activity that does not correspond exactly to the definition of formal education. Non-formal education may therefore take place both within and outside educational institutions, and be suited to persons of all ages*"**.

The term 'non-formal education', was introduced to "*signal a need for creating out-of-school responses to new and differing demands for education*" (La Belle, 1982). In order to not only survive, but to thrive in an ever-changing environment, all through their lives, citizens need to be able to acquire, maintain and further develop their knowledge, skills and abilities. For adults who are outside the formal schooling system, and for children who wish to supplement their formal schooling, the way to acquire these additional skills and abilities is by engaging in informal and non-formal educational activities. Learning does not occur just in the formal classroom, rather the whole world and all the experiences it has to offer can be viewed as a classroom filled with rich and engaging learning opportunities. While formal institutions do contribute significantly to learning, it is not their exclusive purview. It is thus evident that non-formal learning constitutes the most diverse and the most adaptable form of lifelong learning that can have an effective role in improving scientific literacy in our society.

Misconceptions about evolution

The scientific community considers evolution a vital part of science education (National Academy of Sciences, 1998), yet evolutionary theory is one of the most commonly misunderstood areas of biology (Gregory, 2009). These persistent misconceptions about evolution can develop through learning about the subject of evolution in school or from the media, but also from deliberate attempts to misrepresent evolution in public (UC Museum of Paleontology [UCMP], 2021). In order to ensure that the general public is well informed, and that students graduate with an accurate understanding and working knowledge of biological evolution, it is imperative to identify sources of confusion concerning evolution (Modell et al., 2005).

A misconception is defined as **"*a perception of phenomena occurring in the real world which is not consistent with the scientific explanation of the phenomena*"** (Modell et al., 2005).

Evolutionary misconceptions can be grouped into several categories: evolutionary theory and processes, natural selection and adaptation, evolutionary trees, population genetics, evolution and the nature of science, the acceptance of evolution, the implications of evolution, evolution and religion, and teaching evolution (UCMP, 2021).

Although there are many misconceptions about evolution, and many potential ways of introducing or reinforcing evolutionary misconceptions, we will give a general overview of some common misconceptions regarding evolution along with their corrections (Table 1).

***Table 1: Overview of common evolutionary misconceptions**. (Modified from © UC Museum of Paleontology Understanding Evolution (UE) website, licensed under an Attribution-Non-Commercial-Share Alike 4.0 (BY-NC-SA 4.0) Creative Commons Licence). More material and examples are available from Understanding Evolution website at: https://evolution.berkeley.edu/teach-evolution/misconceptions-about-evolution/*

Misconception	**Correction**
Evolution is a theory about the origin of life.	Most of evolutionary biology deals with how life changed *after* its origin, regardless of how life started.
Evolutionary theory implies that life evolved (and continues to evolve) randomly, or by chance.	The process of mutation, which generates genetic variation, is random, but natural selection is non-random.
Evolution results in progress; organisms are always getting better through evolution.	Natural selection does not produce organisms perfectly suited to their environments. It often allows the survival of individuals with a range of traits — individuals that are 'good enough' to survive.
Individual organisms can evolve during a single lifespan	Evolutionary change is based on changes in the genetic makeup of populations over time. Populations, not individual organisms, evolve. Over the course of many generations, natural selection may favour advantageous variants, causing them to become more common in the population.
Evolution only occurs slowly and gradually.	Evolution occurs slowly and gradually, but it can also occur rapidly.
Because evolution is slow, humans cannot influence it.	Evolution sometimes occurs quickly. Since humans often cause major changes in the environment, we are frequently the instigators of evolution in other organisms.
Genetic drift only occurs in small populations.	Genetic drift has a larger effect on small populations, but the process occurs in all populations — large or small. Whether its impact is large or small, genetic drift occurs *all* the time, in *all* populations.
Humans are not currently evolving.	Humans still face challenges to survival and reproduction, just not the same ones that we did 20,000 years ago. The direction, but not the fact of our evolution has changed.

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Species are distinct natural entities, with a clear definition, that can be easily recognized by anyone.	Biological species concept defines a species as a group of individuals that actually or potentially interbreed in nature. For many organisms (e.g., mammals), it works well — but in many other cases, this definition is difficult to apply. The concept of a species is a fuzzy one because humans invented the concept to help get a grasp on the diversity of the natural world.

Although principles of biological evolution are usually taught during primary and/or secondary school, researchers have noted a prevalent presence of misunderstanding of basic evolutionary concepts and mechanisms (Pazza et al., 2010). These misconceptions persist in university students, even after explicit instruction (Bishop & Anderson, 1990).

Although university students' misconceptions about evolution have been noticed almost 50 years ago (Almquist & Cronin, 1988), similar trends are still present. Students 'learn' the theoretical definitions, but their prior scientific misconceptions interfere with acquiring a mechanistic understanding of the evolutionary process (Cunningham & Wescott, 2009). Since it appears that lecturing might not help students overcome their misconceptions, a suggested pedagogical approach would consist of an initial assessment of students' prior knowledge and understanding of evolution, followed by more active learning approaches (like paired problem-solving discussions and constructing concept maps), where students have enough time to actively engage with their learning and thereby actively work towards identifying and rejecting their misconceptions (Cunningham & Wescott, 2009).

Some of the possible causes of common misconceptions

There are multiple reasons documented in literature that help explain why evolutionary misconceptions arise / are reinforced / persist. Some of them are:

- Having an incomplete understanding of evolution and/or not being exposed to empirical evidence that supports evolutionary theory (Smith, 2010);
- Needing to overcome intuitive and naive ways of thinking (Gregory, 2009; Smith, 2010);
- Confusion arising from the inconsistencies in 'everyday' meanings and 'scientific' meaning of words e.g. fitness and adaptation (Alters & Nelson, 2002);
- Issues with the way evolution was initially taught, ranging from being taught non-scientific theories instead of or in conjunction with evolutionary theory (Bowman, 2008), to having been taught to not accept evolutionary theory (BouJaoude et al., 2011);
- Being taught by teachers who themselves did not have a sufficiently strong understanding of the theory (Smith, 2010; Tidon & Lewontin, 2004) or did not accept evolution (Rutledge & Mitchell, 2002);

- Being conceptually misrepresented or being presented as a polarising theory by the media (Pobiner, 2016).

Importance of evolution in non-formal learning

Theodosius Dobzhansky said that "*nothing in biology makes sense, except in the light of evolution*" (Dobzhansky, 1973). Evolution is a unifying theory that helps us understand and explain a multitude of biological phenomena and events that are familiar and influence daily lives. While the theory has a simple elegance, gaining a thorough understanding can be challenging. First of all, it requires one to abandon intuition and grasp some abstract concepts such as randomness (in mutation and genetic drift) (Ziadie & Andrews, 2018). Secondly, some expressions commonly used in the context of evolution, can become language traps as their meaning and usage varies when compared to that in daily conversations (e.g. pressure, force, selection, adaptation and fitness) (Nehm et al., 2010) which can lead to misconceptions (Pobiner, 2016). Such hurdles have made both the teaching and the learning of evolution challenging and subject to controversy (Pobiner, 2016; Ziadie & Andrews, 2018). This in turn makes the progression from novice to expert fraught with difficulty.

An additional, and very important challenge, to furthering evolutionary knowledge is the lack of acceptance of evolution. Kuschmierz and his colleagues carried out a study on the assessment of evolutionary knowledge and acceptance of evolution in Europe and concluded that there is still no standardised assessment Kuschmierz et al., 2020). An American study, however, reveals that, although there is a universal interest in the origin of humans and of life, the subject remains controversial, and the majority of Americans strongly reject biological evolution (Pobiner, 2016). According to the author, the biggest hurdles to understanding and accepting evolution are mistrust and denial of science, cognitive and misunderstandings, language and terminology, a religious view of the world, among others. Education is one clear path by which we can improve both evolutionary knowledge and acceptance.

Education – including evolution education – is typically perceived to occur in a formal setting, in schools and universities. However, such education is often limited to a school-aged population, occurs for a limited timespan (<10% of lifespan is spent in schools), and is inadequate in terms of learning in depth knowledge and skills (NRC, 2009a). Non-formal education on the other hand, is not limited by such criteria and thus has the potential to make evolution education much more accessible.

New smart and innovative learning environments have been developed recently for formal learning such as: flipped classroom, game-based or gesture-based learning, along with pedagogical shifts, such as lifelong learning and separation of learning and competency assessment (Kinshuk et al., 2016), which can do a lot to promote evolution education. However, schools generally do not have resources that would help make evolution education an interesting and interactive experience for students. This lacuna can and has been filled by science-rich non-formal learning institutions, such as museums (Padovani et al., 2013). Museums not only have access to large collections, such as fossils, but also possess necessary expertise in engaging visitors of all ages in non-formal education about evolution.

In addition to providing opportunities for visitors to get a tactile and hands-on experience of millennia of evolution, non-formal learning institutions can also serve as authorities on science and help increase evolution knowledge and acceptance (Branch & Meikle, 2012). Additionally, recent technological advances enable learning in intelligent learning digital environments, which are ideal for use in non-formal education (Kinshuk et al., 2016). The existence of large databases containing biological information, such as, for example, the genomes of a multitude of living or extinct organisms, allows data mining to answer questions about biological evolution, based on bioinformatics and big data analysis. These digital resources could be effectively used to develop non-formal learning activities and spaces.

Evolutionary misconceptions are notoriously difficult to eliminate, and are present even in people who choose to engage with in-formal learning about evolution (Evans et al., 2010; Spiegel et al., 2012), despite the fact that these people are likely to be highly educated and knowledgeable about science (Diamond & Evans, 2007; MacFadden et al., 2007). Non-formal learning experiences can do a lot to address and ameliorate misconceptions (Giusti, 2012), and positive results in increasing evolutionary knowledge have been seen even after a single engagement (Spiegel et al., 2012).

Non-formal evolution learning activities are typically targeted towards building knowledge about a few key evolutionary concepts or addressing particular evolutionary misconceptions, taking a narrow-but deep approach (Giusti, 2012). The same evolutionary concept is reinforced through multiple contexts and redundancy is intentionally built in (Spiegel et al., 2012). This redundancy not only serves to reinforce the main message, but also allows for self-directed learning.

Non-formal evolution activities have the potential to present evolution in a new and startling perspective which could make people curious to learn more – such as this Darwin walk in an IKEA (Groß et al., 2019). Additionally, specifically designed non-formal activities can help increase the relevance of evolution to daily life and thus increase the interest to learn and engage more – such as a museum exhibit on vector-borne diseases (Pickering et al., 2012).

Perhaps one of the most important benefits of non-formal evolution education is that it makes evolution education more accessible and inclusive. While it includes people, who are no longer enrolled in formal education, it more specifically includes people with physical or learning disabilities. Reports from the European Commission on European Disability Expertise for multiple countries have shown that youth with disabilities are more likely to leave school before completion, and that they are far less likely to complete tertiary education than their non-disabled peers (European Commission, n.d.). To provide this population with equitable learning opportunities it is very important to make efforts to increase accessibility to non-formal evolution education, and there are resources available to help non-formal educators do so (Vaz et al., 2020). A very good example of this is an inclusive outreach activity targeted towards helping visually-challenged people learn about phylogenies using multisensory inputs (Laurentino et al., 2021). Another example of inclusivity could be using nature paths to teach students who have conditions relating to attention-deficit and hyperactivity without forcing them to sit in class or in front of a computer.

Implementing non-formal educational activities

Hofstein & Kempa (1985) and Kempa & Diaz (1990) have argued for the benefits of using varying instructional techniques. It is suggested that as students have various interests and motivational characteristics, their preference for the instructional mode and instructional tools varies (Hofstein & Rosenfeld, 1996). Consequently, educators need to consider this diversity of interests and motivations when designing and implementing instructional techniques and content (Hofstein & Rosenfeld, 1996). However, due to limited resources, including time, it is not feasible for educators to explore and cover the entire spectrum of students' differing preferences. It is at this point that students can benefit from having access to and engaging in non-formal science learning. Museums, interactive exhibitions, science festivals, zoos, planetariums could offer great learning opportunities by completing or complementing the official national science curriculum, or presenting new and cutting-edge scientific perspectives outside the curriculum. Such environments are appropriate for the development of non-formal science activities. Simultaneously, Education-Entertainment (E-E) pedagogy, a model which bridges formal education with informal and non-formal educational aspects, can find applications in such environments. "*The E-E model strives to combine the genuine engagement that arises during informal education with the key learning goals that are the domain of formal education*" (de Mora & Kennedy, 2019).

It is important to consider additional factors that could have an impact on participant engagement, and therefore on potential impact, while designing non-formal educational activities. Participants' gender is believed to affect their engagement in non-formal activities. Girls more frequently participate in activities that fall in the domains of arts, biology, chemistry, and physics, whereas boys are found to participate more in computer science activities (Tisza et al., 2019). Age also plays an important role. Tisza et al. (2019), conducted research with 128 educators/non-formal activities' designers from 9 European countries, and concluded that computer science activities are not suitable for nursery-aged children and the goal of 'awareness' is only applicable in activities for the age group of young adults. Ultimately, it is the educator's responsibility to consider the interplay between these factors when combining non-formal activities into the formal curriculum, even if they might find it challenging. Additionally, the role of the educator is of great importance when maximising students' conceptual understanding via non-formal educational activities (DeWitt &

Osborne, 2007). Since, it is noted that most teachers are unfamiliar with the effective implementation of these learning settings (Anderson et al., 2006), better preparation and specific examples would be of great help for educators (Olson et al., 2001). This would additionally empower formal educators to be much more effective when addressing student audiences by implementing well-designed teaching strategies from non-formal learning settings (Çil et al., 2016).

Specifically, talking about evolution and non-formal activities designed to contribute to its understanding, Record (2018) suggests philosophical and epistemological obstacles can be overcome by "*understanding visitor audience motivations, prior knowledge, and misconceptions, and addressing these barriers through design informed by interpretive practices*".

Based on the factors mentioned above, and considering both that understanding evolution is an integral part of scientific literacy, and that non-formal learning activities contribute to lifelong learning, we propose that gathering and evaluating existing evolution-themed non-formal educational activities would enrich educators' instructional techniques and lead to improvement of their students' learning outcomes.

Interest groups

Non-formal education is a fundamental part of lifelong learning, and aims at providing people with opportunities to acquire, maintain and further develop the skills and competencies they need to be responsible citizens (Paraskeva-Hadjichambi D. et al. 2020). The landscape of non-formal education is very diverse; therefore, the clear distinction of interest groups cannot be achieved.

The most obvious distinction is between the participants of the non-formal activity (target groups) and the producers of the non-formal education activities (actors involved). In the non-formal education landscape, those two groups intermingle during the iterative process of creating, participating, and modifying.

Target groups

Among participants of the non-formal activities, the most prominent group is young people. In an educational and learning context, the distinction is more specific, and the main categories are divided according to age:

- Children in kindergarten / preschool: ages 2 - 6 years
- Children in elementary education: ages 7 - 12 years
- Young people in secondary education: ages 12 - 16 years
- Adults: over 17 years old. (including university students)

The ages given above for children in kindergarten, elementary and secondary school are not the equivalent in all countries, regions and contexts. Each category is sometimes separated into subcategories, depending on the specific non-formal education activity, its goals or necessary prior knowledge.

Actors involved

"*A learning ecology is a physical, social, and cultural context in which learning takes place, over time*" (Bevan, 2016). To imagine the complexity of actors that are involved in a complex learning ecology, we can picture certain formal educators who propose learning modules that extend outside of the classroom to home setting (informal learning) and could involve a visit to a non-formal learning institution (a museum or a science centre). The challenge of educators in complex learning ecosystems is how to create and leverage a rich formal and non-formal learning environment that supports the change of the individual's motivation and interests through time (Paraskeva-Hadjichambi et al., 2020)

Among the producers of the non-formal education activities we can thus identify several categories:

- Teaching staff and professionals within school education,
- Researchers,
- Museum curators and professionals,
- Science communicators
- Scientific game designers
- Artists and graphic designers
- Virtual educational content developers
- Civil society organisations,
- Librarians,
- Hobbyists.

Activities and Examples

Creating evolution-themed workshops

The term workshop originally referred to a location where goods were fabricated or repaired. The meaning of the term has since evolved to refer to events during which a group of people assemble to gain knowledge or skills (Ørngreen & Levinsen, 2017), by actively engaging in a practical activity. While workshops can differ in many ways, they have some commonalities. They are typically of a short duration, targeted towards people with some commonality, are facilitated by an expert in the field, have a very low participant-facilitator ratio, and usually result in a product (new ideas, improved skills etc.) (Ørngreen & Levinsen, 2017). Additionally, workshops can also be used as part of a research methodology such as participatory research (Mor et al., 2012; Öberg & Hernwall, 2016; Phaal et al., 2007).

There is no universally ideal design for workshops - situational variables determine the suitability of a design. Each workshop's style and character will be determined by various factors including: target audience, learning objectives, practical activities designed to achieve the learning objectives, methods of evaluation and availability of resources (including facilitators). Traditionally, workshops were held in-person and therefore were limited to people who could attend physically. Accessibility to workshops has increased with an increasing number of workshops being offered online, such as those offered by the Natural History Museum, London (Virtual Evolution Workshop: https://www.nhm.ac.uk/events/schools-virtual-evolution-workshop.html) and the Museo Nazionale della Scienza e della Tecnologia Leonardo da Vinci (https://www.museoscienza.org/en/offer/interactive-laboratories).

Evolution-themed workshops are commonly offered by non-formal learning centres (e.g. museums & science centres) to complement the formal education curricula for school students (Hausamann, 2012; Seybold et al., 2014). Another common category is workshops as professional development for formal educators to help them become better educators. Portuguese science teachers have participated in workshops that teach them how to leverage the game 'Influenza: an evolving virus' (Nogueira & Ponce, 2021) to teach concepts such as biological evolution, parasite-host coevolution, and the use of vaccines as a tool for infectious disease control (Workshops para professores – XV Encontro Nacional de Biologia Evolutiva). In another workshop, 'SimulATe to model the outcomes of bacterial infections', teachers learn to use the SimulATe software (David et al, 2019), to explore the natural selection exerted by antibiotics on bacterial populations, and the subsequent consequences for human health. Some of the authors of this publication designed and conducted a set of two online workshops. The first, Evolution decoded (WG3 EuroScitizen, 2022a), was designed to introduce non-formal educators to online tools that they can use to enhance their evolution-themed activities. And the second, Assessment decoded (WG3 EuroScitizen, 2022b), was designed to help them incorporate assessments into their activities.

Research has shown that well designed workshops can lead to gains in knowledge and skills in the participants, increased interest in the topics, as well as changes in attitudes (Kirch et al., 2005; Miller et al., 2009; Yanowitz & Vanderpool, 2004). Participants also tend to retain the knowledge and skills they learned for a long time (Seybold et al., 2014). With respect to evolution in particular, workshops have been shown to increase both conceptual knowledge of evolution and acceptance of evolution (Schrein et.al, 2009).

For an example of an evolution-themed workshop see: Workshop "Human Evolution"

To find further examples of evolution-themed workshops visit http://evodash.eu/.

Creating evolution-themed educational trails or nature paths

An educational trail/ natural path is an intentionally constructed route designed to focus on a specific topic (Clark, 1997). They are typically meant for participants to walk through, but could also be designed for bicycles. The trails can highlight ideas related to local biology, geology, cultures, customs etc. However, they can also be used to spotlight evolutionary topics. Nature paths can be extremely useful to illustrate and explain the magnitude of evolutionary time and compare evolutionary timescales (e.g. macro v microevolution) by using geological time and physical distances as analogies (Dodick, 2007; Karlstrom et al., 2008).

Educational trails/Nature paths could have optimal outcomes if they are designed with the principles of place-based education in mind. Place-based education leverages local assets – including cultural, environmental, and physical resources (Smith, 2007). It has a long and rich tradition dating back to the ancient Greek philosophers (Stickney, 2020). One of the major strengths of place-based education is that it can be contextualised to the needs of the local learners and to their experiences. And since people learn best when they find the material relatable and relevant, using place-based learning will improve learning outcomes (Smith, 2002). It is important to note though that place-based learning does not exclude any knowledge and skills that do not directly pertain to that local community, it just includes the ones that do.

Since educational/nature paths are primarily intended to be self-paced and self-directed they have to be designed with multiple audiences in mind (NRC, 2009b). The participants could have a wide variety of lived experiences, knowledge, or even attitudes about evolution. The potential diversity of entrance narratives (Doering & Pekarik, 1996) that the path designers have to consider could be very large indeed. To this end, therefore, it might be advisable to present a few key concepts in multiple formats and at multiple instances to increase the chances of the message being relevant and relatable to, and retained by the participants.

Additionally, it is important to consider that many participants will walk the path with their family or friends. Therefore, it is important that they are provided not only with opportunities to passively absorb information, but to actively and collaboratively enhance their knowledge and understanding (Karlstrom et al., 2008).

For an example of an evolution-themed workshop see: Workshop "Human Evolution"

To find examples of evolution-themed educational trails and nature paths visit http://evodash.eu/.

Creating evolution-themed exhibitions, exhibits, and info boards

For the purposes of this document:

- **An exhibition** is typically a location or an event during which a collection of items that have some commonality are displayed to the public. While some evolution-themed exhibitions are permanent (like those in natural history museums), many are temporary and/or travelling in nature (e.g. 'evolution happens!' exhibition described in the examples section of this document).
- **An exhibit** is one item or object that is either exhibited by itself or as part of a larger exhibition. An example of an evolution-themed exhibit could be a display case showing morphological differences in hominid skulls.
- **An info board** is a large 2-dimensional exhibit. Info boards can exist by themselves, or as part of a series on a particular topic. An example of an evolution-themed info board could be a large infographic of phylogenetic relationships of the coronavirus variants, or a board with information about fossils found in the locality.

Although most of the research on non-formal education using exhibitions, exhibits, or info boards is mainly focused on exhibitions, the main takeaways are applicable across the board.

Some defining features of exhibitions, exhibits and info boards are that they have to be designed with a wide range of potential audiences in mind and considering the fact that the audience will be primarily "*self-directed, voluntary, and guided by individual needs and interests"* (Falk & Dierking 2002; NRC, 2009a). Since visitors can choose to spend as much time or as little time and interact with as many or as few of the exhibits as they like, it is therefore important to design opportunities to increase visitors' engagement. While there is no 'best' strategy to structure an evolution-themed exhibition, Diamond & Scotchmoor (2006) suggest that the following five themes could be used to design these exhibitions: Geological Time, Fossil Assemblages, Systematics, Mechanisms of

Evolution, and Historical Approaches. Additionally, it is essential to build redundancy, with the main message being presented repeatedly and in multiple formats (Spiegel et al., 2012).

Designing evolution-themed exhibits and info boards brings with it a unique set of challenges – although unintentionally, some exhibitions can actually reinforce evolutionary misconceptions. Some studies have shown that visitors to exhibits of human evolution misinterpret evolutionary history as ‘progress’ (Scott, 2005; Scott & Giusti, 2006).

One important challenge while designing exhibitions, exhibits and info boards is to make the message relatable and relevant to the potential audience. This can be achieved by designing the material to elicit emotions, by linking them to concerns that are relatable and relevant to the audience such as “*local, cultural, societal, environmental, economic and political”* issues (NRC, 2009a; Smith, 2007), or especially in the case of evolution – by humanising it (Diamond & Scotchmoor, 2006). Well-designed exhibitions and info boards can provide both an entertaining and an educative environment for people, and studies have shown that people value such spaces and are willing to spend their leisure time engaged with the material displayed (Briseño-Garzón et al., 2007; Ivanova, 2003). Additionally, leveraging contexts that are of interest to the target population can motivate learners to seek to further develop the knowledge about the non-formal activity’s main message (Barron, 2006: NRC, 2009a).

Many studies have highlighted the impacts of engaging in non-formal learning by visiting exhibitions as a complement to formal education. Positive outcomes have been documented with respect to gains in scientific knowledge and attitudes (Falk & Dierking, 1997). These outcomes can be further enhanced by preparing the students in advance and debriefing after the visit (Anderson et al., 2000, 2006). Additionally, learning gains were increased when the visitors had the opportunity to actively engage with the exhibits (Price & Hein, 1991).

Traditionally, exhibitions, exhibits and info boards are physical objects that can only be accessed by people in the geographic vicinity. However, there is an increasing trend towards making content available through virtual exhibitions and tours (e.g. Virtual tours at the Smithsonian: https://naturalhistory.si.edu/visit/virtual-tour or at The Natural History Museum, London: https://www.nhm.ac.uk/visit/virtual-museum.html). Such efforts can help increase the reach and accessibility of the content developed by non-formal educators (Khoon & Ramaiah, 2008) and provide a more customisable experience (Diamond & Scotchmoor, 2006).

For examples of evolution-themed exhibitions and exhibits see: Exhibition “evolution happens!” and THE WORLD IN A RUCKSACK. 100 Years of Natural Science Expeditions

To find further examples of evolution-themed exhibitions, exhibits, and info-boards visit http://evodash.eu/.

Creating evolution-themed Citizen Science projects

Over the last decade 'citizen science' has gained ground as a research technique that engages the public in gathering scientific information (Bonney et al., 2009), and aims to develop both scientific knowledge and skills (National Academies of Sciences, Engineering, and Medicine [NASEM], 2018). However, it is not a new phenomenon. Some of the earliest citizen science that we know of occurred around 2000 years ago when Chinese civilians tracked the migratory patterns of locusts that would cause huge losses to harvests (Irwin, 2018). It can be argued that some of the most famous 'scientists', including possibly the most famous evolutionary scientist, Charles Darwin, were actually citizen scientists since science was not their primary profession (Silvertown, 2009).

Citizen scientists are typically volunteers, who are not trained as professional scientists, but who get involved in scientific research taking part in related projects (Cohn, 2008; Dickinson et al., 2010). Specifically, volunteers contribute either by collecting or processing data, or both (Silvertown, 2009). This technique aims not only to fulfil scientific goals, but also to align with the volunteers' motivations. According to Crall et al. (2013), "*citizen science program participants appear to be more scientifically literate than the general population"*. This means that through the exploration of the physical world, citizen scientists reflect on science, gain scientific knowledge, and seem more capable of using scientific reasoning to make informed decisions (Bonney et al., 2009). In other words, citizen science has a positive correlation with public understanding of science (Bonney et al., 2016). While citizen science projects typically involve adults or people outside the formal schooling system, they also have the potential to be integrated into school curricula and other educational programs (Bonney et al., 2016). However, according to the same authors, "*curriculum projects must provide significant support and training for teachers, particularly if the projects emphasise inquiry-based learning. Furthermore, many teachers won't or can't adopt projects that are not aligned to state and/or national standards*".

Unfortunately, there is a paucity of evolution-themed citizen science activities that have been documented in the literature (Brandt et al., 2022). Worthington et al. (2012) conducted an evolution-themed citizen science project called 'Evolution MegaLab', which included 15 European countries. This project aimed to help survey shell polymorphism in two different species of banded snails to detect possible evolutionary change after comparison with historical data. The whole project took place in the light of Charles Darwin's double centenary. Worthington et al. (2012) state that "*the critical tasks achieved by the Evolution MegaLab that any citizen science project must tackle are as follows: (i) design of an appropriate project, (ii) recruitment, motivation and training of volunteers, and (iii) ensuring data quality*". In addition, participants need to be particularly aware of the scientific process so as to enhance their understanding (Brossard et al., 2005). In this project, a quiz was used to measure data quality, but such quizzes can also be used to evaluate learning outcomes. It is worth highlighting that there are few citizen science projects that focus exclusively on evolution.

For guidelines focusing on the development of citizen science projects that promote scientific literacy in evolution, refer to Brandt et. al. (2022)

The benefits of engaging in citizen science are many. In the last few years, thousands of scientific peer-reviewed papers have been published based on data collected through citizen science efforts (Irwin, 2018). Additionally, such projects can be leveraged to educate and engage the public about relevant scientific issues. However, citizen science comes with a few challenges, including managing the volunteers, quality controlling the data, as well as recruiting and motivating the volunteers to persist for the duration of the project (Gura, 2013).

For examples of evolution-themed citizen science projects see: Obtectus Finders (Opasulji se)

To find examples of evolution-themed citizen science projects visit http://evodash.eu/

Creating evolution-themed games

The increasing use of games, mainly digital games, by children and adults has attracted the interest of researchers, curriculum designers and educators in formal and non-formal education. Prior research has explored the use and effectiveness of games in the educational process (Hwang et al., 2012; Li & Tsai, 2013; Sadler et al., 2013; Sung et al., 2013). Although it has been shown that educational games can bring positive results for both teachers and students at all levels of education, some researchers are sceptical about the resultant learning outcomes (Annetta et al., 2009; Onisiforou, 2014). Learning benefits can be enhanced by designing and selecting games that best match the learning goals, and by ensuring that these learning goals also map onto the subsequent assessments (Hogle, 1996; Rastegarpour & Marashi, 2012).

Recently, researchers collected and analysed evolution-themed board games, emphasising their teaching and learning potential (Muell et al., 2020). They found that each game offered different learning opportunities of the evolutionary concepts that could be explored while playing and during post-game debriefings and that "*students greatly benefited from guided discussions on how each game succeeded and failed in emulating the core evolutionary concepts, which promoted critical thought by encouraging students to reflect on the experience*". Board games offer an "*interactive and fun experience for many types of curricula"* (Taspinar et al., 2016) and have the potential to be both educative and entertaining, and as such, biology educators are highly encouraged to use them.

The diversity and availability of evolution-themed games is increasing, and here we present a few examples from different European countries that can be used both inside and outside of the classroom:

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- **Influenza: an evolving virus** (Nogueira & Ponce, 2021, https://zenodo.org/record/5809065) is a card game that can be freely downloaded in multiple European languages. In the game, players explore the zoonotic transmission of different variants of the influenza virus, genome rearrangement events and mutations that generate variants capable of subverting the immune response.

- Another card game- **Beat Corona** - explores the zoonotic transmission of animal and human coronavirus and its evolution with playing cards on the viral evolution of the Coronavírus. It was developed by a team of both Portuguese and English institutions (https://projects.iniav.pt/CORONAVIRUS/home). Beat Corona is accompanied by a book (available in multiple European languages) that will help teachers use the game to support their teaching of evolutionary concepts (Duarte et al, 2021).

- The Turkish board game **Evrim: Bilimsel Kutulu Masa Oyunu** (Evolution: Scientific Board Game: https://evrimagaci.org/bilimsel-gerceklere-dayanarak-hazirlanmis-masa-ustu-oyunu-evrim-52) encourages players to explore evolutionary concepts such as natural selection, and to confront some evolutionary misconceptions.

- At the Museum of Zoology, Athens visitors can play a video game - **Wild flights** - while visiting the bird exhibits and learn more about biotopes, birds' features, and structure and function in the light of evolution (Gata et al., 2022).

- '**Terra Evolution'** (tree of life https://boardgamegeek.com/boardgame/111426/terra-evolution-tree-life) is a board game that comes from Finland. It is a fast-paced strategic deck/world-building game about the evolution of species, cataclysms, and extinction with strong and exciting interaction between players.

While most of the games described here are available as physical products, there is a demand for online versions of these games as well. In the light of the recent pandemic, there has been an explosion of websites which allow visitors to play traditional board games in an online format. For example, commercially successful board games such as Dominant Species, Pandemic, Evolution, and Oceans are now available through gaming websites (e.g. tabletopia.com, boardgamearena.com) and as apps (through GooglePlay and Apple App Store).

For an example of an evolution-themed game see: Influenza: an evolving virus

To find further examples of evolution-themed games visit http://evodash.eu/

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Creating evolution-themed MOOCs

Massive Open Online Courses (MOOCs) are "designed for a large number of participants and can be accessed by anyone anywhere, as long as they have an internet connection. Most MOOCs are open to everyone without entry qualifications, and offer a complete course experience online for free" (Witthaus et al., 2016). They offer guided self-learning possibilities and allow participants to learn at a pace most suitable for the participant's needs. MOOCs have therefore been described as tools to democratise learning for everyone (Christensen et al., 2013), but this has shown to be far from true. Most successful participants of MOOCs are actually highly educated and employed individuals from developed countries (Christensen et al., 2013).

Nevertheless, MOOCs offer a way to reach a broader audience with relevant scientific content, structured in a familiar way of a scheduled class, but without the physical constraints. The course level is usually targeted at undergraduate students, which makes it accessible for a broad range of young adults and lifelong learners, as long as they are motivated enough by the topic to follow the course.

When in search of a MOOC the webpage https://www.mooc-list.com/ is a handy place to start. It lists the upcoming MOOCs and Free Online Courses that start in the next 30 days. It provides easy search tools, which help to navigate through different opportunities. The page lists courses from Coursera, edX, FutureLearn and other content providers and Universities in a wide range of categories and subjects, including evolution-themed courses.

The duration of the courses and the weekly effort required to complete the course varies between the courses, but on average the courses usually last from 2 to 14 weeks and require around 2 to 10 hours per week of learning activities. Learning activities include lectures, tests, self-reflection tasks, contributing to discussion forums, writing short essays and peer evaluations.

Examples of two major platforms offering free anglophone evolution-themed MOOCs are:

Coursera (www.coursera.com) is a "social entrepreneurship company that partners with the top universities in the world". It was established by two Stanford professors and has contracts with 33 universities. Some examples of evolution-themed MOOCs offered by Coursera are: Introduction to Genetics and Evolution (4 weeks), Evolution: A Course for Educators (4 weeks).

FutureLearn (www.futurelearn.com) was established in late 2012. As of October 2013, it had 26 University partners and three non-university partners: the British Museum, the British Council and the British Library. Some examples of evolution-themed MOOCs offered by FutureLearn are: Understanding and Teaching Evolution (3 weeks), Teaching Primary Biology: Evolution and Inheritance (2 weeks).

The effectiveness of the MOOC also depends on the motivation of the participant. In a recent study that explored various factors that affected the retention of participants for the duration of the MOOC, researchers found that in addition to course content, interaction with the instructors greatly affected participants choosing to complete the MOOC or not (Hone & El Said, 2016). Another study that explored student satisfaction indicated that in addition to the instructor and content, the schedule of the MOOC also affects student satisfaction (Hew et al, 2020).

For an example of an evolution-themed MOOC see: Evolution: A Course for Educators

To find examples of evolution-themed MOOCs visit http://evodash.eu/

Creating evolution-themed art activities

Art can be seen as "*a system of human communication arising from symbolic cognition, conveying ideas, experiences, and feelings"* (Cipriani et al., 2019). Art challenges our views of the world (Haahr, 2004), and as such could serve as a perfect medium to address misconceptions about science in general, and about evolution in particular.

Collaborations between artists and scientists combine art and science, with the aim to benefit both the parties involved. Art, science and technology are now more intertwined than they have ever been. Today art and artists are influenced by trends, ideas and cultures from all around the world, and creatively use rapidly advancing, cutting-edge technology and innovative materials. They find new ways to use old media, as well as invent new ones. The impact of technology on contemporary art is hard to pin down, as they are evolving and changing so quickly.

Art can enhance science learning by providing a more authentic and engaging experience for the learner. "*Visual, spatial, and graphic arts have the potential to present science and culture in a distinct manner that is complementary to the more traditional ways of understanding science"* (Segarra et al., 2018), and they have been part of educational repertoires for some time (Braund and Reiss, 2019). The artistic approach uses a variety of new media literacies, skills and technologies. It aligns with the 21-century call for interdisciplinary education, already taking place across the world within the STEAM (science, technology, engineering, art, and mathematics) framework (Land, 2013). Projects included in these educational initiatives deliver scientific content while having art as a central point, providing a different point of view on the natural world. The STEAM framework objective is for science to become "*more inclusive and accessible to a broader audience, while clarifying the meaning of scientific concepts and culture and fostering collaborative works in art and science"* (Segarra et al., 2018). When combined with a non-formal learning environment, such a collaboration of art and science results in an increased sense of wonder, interest and motivation in scientific topics (Peleg & Baram-Tsabari, 2011).

Teaching science through performing arts contributes to learning through a combination of visual, auditory and kinaesthetic experiences. Overton and Chatzichristodoulou (2010) stress the value of engaging with science concepts through performing arts, especially when coupled with the students' interpretation or presentation, enhancing both fine and gross motor skills. Even if there is little research on applications of performing arts in science, there is some documentation on educational science theatre productions (Overton & Chatzichristodoulou, 2010; Peleg & Baram-Tsabari, 2011; Wieringa et al., 2011). All research agrees on the benefits of such live performances, which can potentially reach a wide audience, raise awareness about science topics and engage both performers and spectators in an experiential learning activity.

Today's visual art STEAM approaches emerge from the older learning traditions - many of which include aesthetics, visual literacy, and communication (Bequette & Bequette 2012).

Visual representations of organisms have always been an important tool in learning and communicating biology and evolution. However, Darwinian evolution has been and remains a challenge for art. Many of the concepts in evolutionary theory are abstract and hard to visualise or represent through simple illustrations. Artists initially responded to Darwin's theory by confusing it with other evolutionary theories and non-scientific ideas that were common at that time (Lubbock, 2008). Nevertheless, visual arts have also played a significant role in the development of evolutionary theory. A prominent artist whose work has helped develop, visualise and thereby promote evolution education is John Gould with his sketches of Darwin's finches that appear in Darwin's account of his travels aboard the H.M.S. Beagle (Darwin, 1845, p 379). Another artist, Ernst Haeckel (Haeckel, 1877), helped further underline the concept of a common ancestor by explicitly depicting structural similarities between the early-stage embryos of multiple species. Some contemporary artists explore evolution through art by paying homage to our origins, such is the work of Lynn Sures, "*who uses print and papermaking to depict the fossil records of early human evolution"* (Tayag & Wells, 2014). Others embrace randomised and chaotic compositions as modern forms of the understanding of evolution. "*The symbolist figurative art of C. Bangs goes even further into our evolutionary past, looking at our molecular origins in the cosmos*" (Tayag & Wells, 2014).

Educators teaching evolution should however be careful with the artistic approach, since its subjectivity could lead to reinforcement of the misconceptions about evolution. But, as we understand the theory of evolution further and better, the art inspired by it, as well as the relationship between art and evolution, will also change and improve.

For examples of evolution-themed art activities see: Darwin's Sex Tape (La Sextape du Darwin), 2018 and Endless Forms: Charles Darwin, Natural Science and the Visual Arts, 2009

To find examples of evolution-themed art activities visit http://evodash.eu/

Creating evolution-themed public outreach events

Public outreach events can span the scale from small, local events that target a small section of the local community, to large public events that attract thousands of participants. While large public events (e.g. Science festivals) have been taking place in Europe for almost 2 centuries, in the recent past they have exploded in terms of number, diversity as well as scale. (British Science Association, n.d.; Cassidy, 2006). Bultitude et al. (2011) proposed some defining features of 'Science Festivals': They are time-limited and recurring, they have common themes, their purpose is to engage audiences (especially non-scientific audiences) with scientific content, and most of all, they are intended to be a celebration of science. In addition to promoting general scientific knowledge, Science Festivals are excellent events to disseminate knowledge about new, exciting and relevant development in science to the general public. Events that are described as science festivals, with a specific impact on the scientific literacy of the audience in the context of evolution, have similar objectives: to educate and excite the public about evolutionary science.

One defining characteristic of science festivals (and outreach events in general) is their ephemeral nature. The impermanence ensures that the organisers are able to maintain their energy and drive, and that the participants have a sense of occasion and excitement (Derrett, 2004; Wiehe, 2014).

Since events like science festivals are usually funded by public money, it is important to understand if and how they are beneficial to the general public. Although historically, this was a question that was not explored, there are an increasing number of recent studies that provide evidence to support further investment of time, money, and energy into such events. Some are listed below:

- Science festival participants reported long-term gains in knowledge (learnt something new), attitudes (feeling more connected to science, increasing interest in science) and scientific behaviours (following up on information, continuing engaging with science). These learning outcomes increased when the participants actually interacted with science professionals. (Jensen & Buckley, 2014; Science Festival Alliance [SFA], n.d.).

- Science festival organisers reported benefits both professionally (reaching larger audiences, increased interaction post-event) and personally (increased public interaction skills). (SFA, n.d.)

- Science festivals have the potential to decrease inequities in access to science. An American study reports that even after accounting for census data for the location, Science festivals attracted a disproportionately higher number of underrepresented groups including ethnic minorities and women (SFA, n.d.). However, research from Kennedy et al. (2018) at three UK science festivals shows a very different trend. They reported that the audience at those festivals was disproportionately economically privileged and highly educated people as compared to the general population.

While planning the festival it is therefore important to consider how best to target the population that would benefit the most from attending such an event. Ideally, we would want non-formal activities like science festivals to help make science more accessible to everyone.

Darwin Day

The annual international celebration of the life and work of Charles Darwin on February 12th, 'Darwin Day', includes various evolution-themed events. The initiative started in 2011 to recognize Charles Darwin "*as a worthy symbol to celebrate the achievements of reason, science, and the advancement of human knowledge, with the broader sense of acknowledging the importance of science in the betterment of humanity"* (Stark, 2011).

Darwin Day is a very effective tool to initiate and develop relationships with the community. Crivellaro and Sperduti, (2014) described one of the events organised as a celebration of Darwin Day in Rome in 2013. Similar to what has been observed by other researchers (Evans et al., 2010; Spiegel et al., 2006) the venue attracted people that were in general, higher educated, and more receptive to science and education than the general populace.

European Researchers' Night

European Researchers' Night is a type of science festival intended to bring researchers and their work closer to the general public and to encourage youth to pursue science - as an interest and as a profession (European Commission, Directorate-General for Education, Youth, Sport and Culture, 2017). It is held annually on the last Friday of September across Europe, with over one million participants every year (European Commission, Directorate-General for Education, Youth, Sport and Culture, 2017). Every year there are a number of different activities including hands-on experiments, guided tours of research labs, talks, debates, panel discussions, interactive demonstrations, and workshops.

The European Researchers' Night is an outstanding opportunity to present evolutionary content to the general public. EvoCorner, an activity, was specially designed and introduced in 2017 to the European Researchers' Night visitors in Serbia (Kenig et al., 2019). It offered a concept of migration in an evolutionary sense, provided scientific information about evolutionary theory, and showed the importance of genetic variation to visitors. In addition, visitors were able to play a board game named Bird Migrations with researchers on-site.

For an example of an evolution-themed outreach event see: Sex & Bugs & Rock 'n Roll

To find further examples of evolution-themed public outreach events visit http://evodash.eu/

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Workshop "Human Evolution"

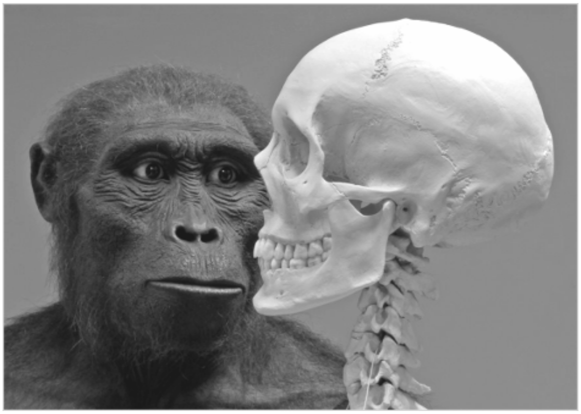

Image by Carola Radtke, MfN Berlin

Group of activities: **Hands-on**

Type of the activity: **Workshops**

Country: **Germany**

Facilitators: **Museum educators**

Participants / target audience: **Teenagers from age 15**

Location: **Museum für Naturkunde Berlin, Germany**

Pre- knowledge: **Not required**

Duration: **100-120 minutes**

Permanent activity: **Yes**

More information: **available in German or English**

https://www.museumfuernaturkunde.berlin/en/museum/education/school-and-kindergarten/workshops-and-microscopy

Short description of the activity:

In this workshop, students compare the casts of skulls of various representatives of the genera Australopithecus and Homo and learn to recognize the characteristics by which they differ. The workshop consists of four parts:

1. Introduction in human evolution
2. On the way to the human being Group work/partnership (students): skull comparison human - gorilla.
3. Hominini – man and his predecessors Group work/partnership (students): Species identification of a Hominini skull
4. Sex determination on the human skull

Evolutionary concept / topic / theme:

Human evolution

Content:

Human evolution has a particular fascination for most people. The tree of life of human beings is redrawn nearly every year.

Assessment

Could the activity be assessed? **Yes**

How and when to assess the activity? **Before and after the activity**

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The Grand Bazaar of Evolution

Image by Natural History Museum of Geneva

Group of activities: **Unsupervised self-paced**

Type of the activity: **Educational / nature paths**

Country: **Switzerland**

Facilitators: **Mostly self-guided, with some periodic guided tours offered**

Participants / target audience: **All visitors to the botanical garden**

Location: **Conservatory and Botanical Garden of the City of Geneva**

Pre- knowledge: **Not requested**

Duration: **N/A**

Permanent activity: **No; May 20 - 17th October 2021**

More information:

https://www.cjbg.ch/fr/media/455/download?attachment

Short description of the activity:

An outdoor exhibition that uses plants to illustrate various evolutionary concepts. The path is divided into four major themes. The first one depicts evolutionary time and locates key evolutionary milestones. The second theme explores the mechanisms of evolution. The third theme talks about how we study evolution, and the fourth and final set of installations talk about the influence of humans on the course of evolution.

Evolutionary concept / topic / theme:

Evolutionary time, genetic variation, convergent and human-driven evolution,

Content:

The curators used Euphorbs and Cacti to talk about convergent evolution, and a climbing wall to depict plants adapted to different altitudes. Also, they used installations in Lake Leman to show that life originated in water, and a ‘walk-on’ cladogram that leads to major diversification of plant organs.

Assessment

Could the activity be assessed? **Yes, if there are guided tours. No, if the activity is self-guided.**

How and when to assess the activity? **Before, during and after the activity**

Exhibition "evolution happens!"

Image by Joelyn de Lima

Group of activities: **Unsupervised self-paced**

Type of the activity: **Travelling Exhibition**

Country: **Switzerland**

Facilitators: **Self-guided**

Participants / target audience: **Ages 12-16**

Location: **Zoological Museum, University of Zurich, Zurich Switzerland**

Pre- knowledge: **Not required**

Duration: **30 - 75 minutes**

Permanent activity: **No, Summer 2021 - Feb 2022 at the first location. Will be exhibited at the next location from Fall 2022.**

More information: Website **available in German or English**

Short description of the activity:

In this exhibition, 7 case studies from literature have been used to reinforce the main message that although evolution can happen over millennia, it can also happen very quickly. The designers have used prominent examples that highlight how evolution can be a rapid process. Some of the examples used are very relatable to the local Swiss population.

Evolutionary concept / topic / theme:

Evolutionary time scales

Local examples

Content:

Evolution can happen very quickly.

There are several factors that influence evolution including mutations, variations, heritability and selection.

Evolution is happening around us - illustrated by using local case-studies.

Assessment

Could the activity be assessed? **Yes**

How and when to assess the activity? **Before, during, and after the activity**

THE WORLD IN A RUCKSACK. 100 Years of Natural Science Expeditions

Image by University of Tartu Natural History Museum

Group of activities: **Unsupervised self-paced**

Type of the activity: **Exhibits / Info boards**

Country: **Estonia**

Facilitators: **Scientists, Staff of University of Tartu Natural History Museum**

Participants / target audience: **All age groups are welcome**

Location: **University of Tartu Natural History Museum**

Pre- knowledge: **Not required**

Duration**: Up to 1 hour**

Permanent activity: **N**o

More information:

https://elurikkus.ee/en/maailm-seljakotis

Short description of the activity:

Showing and explaining the methods that scientists, during the history of Estonia, have used and still are using to study nature.

Evolutionary concept / topic / theme:

History of the expeditions by Estonian scientists to study patterns of life, species' diversity and macroevolution.

Content:

The exhibition gives an overview of the development trends of Estonian natural science during the last century, as seen through scientific expeditions. The exhibition focuses on the fields of geology, zoology, botany and mycology, where the material brought from the expeditions is stored in scientific collections for further research to tell the story of evolution of life on earth. Nearly 900 new species have been discovered by scientists, and their findings show that research has led our scientists on expeditions around the world.

Assessment

Could the activity be assessed? **Yes**

How and when to assess the activity? **Possible to pre and post assess with tools.**

Obtectus Finders (Opasulji se)

Image by opasuljise.rs

Group of activities: **Hands-on**

Type of the activity: **Citizen science**

Country: **Serbia**

Facilitators: **Researchers**

Participants / target audience: **Elementary school students, secondary education students, university students, adults, teachers/educators**

Location: **Anywhere**

Pre- knowledge: **None**

Duration: **30 min**

Permanent activity: **No**

More information:

http://www.opasuljise.rs/en/

Short description of the activity:

The citizen science project Obtectus Finders is based on citizens' contributions to a population-genetic study of seed beetles. The contribution is based on catching and submitting seed beetles (*Acanthoscelides obtectus*).

Evolutionary concept / topic / theme:

Biodiversity, species,

Content:

The citizen science project Obtectus Finders aims to capture seed beetles from various locations in order to analyse the genetic diversity of their populations. The scientists can collect beetles from several natural populations, but there are too few of them to collect samples from enough places. The project invites people of all ages and backgrounds to participate in real scientific research. The samples that citizens send, will directly contribute to the seed beetle genetic research and help detect the distribution of this pest insect.

Assessment

Could the activity be assessed? **Yes**

How and when to assess the activity? **Before and after the activity using a short survey**

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Influenza: an evolving virus

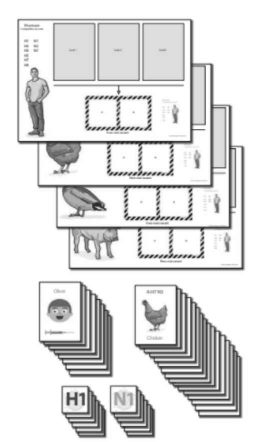

Image by Alexandre Algarvio

Group of activities: **Hands-on**

Type of the activity: **Games**

Country: **Portugal**

Facilitators: **Students**

Participants / target audience: **Secondary education students, university students/tertiary education, adults, teachers/educators**

Location: **Anywhere**

Pre- knowledge: **General notions of mutation, selection, infection — the information presented in the accompanying booklet**

Duration: **~30 minutes**

Permanent activity: **No**

More information:

https://doi.org/10.5281/zenodo.5809065

Short description of the activity:

Players play a card game that explores the zoonotic transmission of different influenza virus variants, genome rearrangement events and genetic mutations that generate new variants capable of subverting the immune response-adaptive advantage. Players experience the generation of new virus variants capable of infecting humans.

Evolutionary concept / topic / theme:

Genome evolution by reassortment and mutation

Content:

An e-book containing the rules of the game, and a board game with a deck of cards. Available in multiple European languages.

Assessment

Could the activity be assessed? **Yes**

How and when to assess the activity? **Before and after the activity**

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Evolution: A Course for Educators

Image by Coursera

Group of activities: **Non-institutionalised wide-audience education**

Type of the activity: **Massive Open Online Courses (MOOCs)**

Country: **Designed by American Museum of Natural History in the USA, open to everybody**

Facilitators: **Staff of American Museum of Natural History**

Participants / target audience: **Teachers, people involved in teaching, lecturing**

Location: **Online at coursera.org**

Pre- knowledge: **Officially not required, but some basic level would be helpful.**

Duration: **4 weeks**

Permanent activity: **Yes**

More information: https://www.coursera.org/learn/teaching-evolution

Short description of the activity:

The 4-week online course covers the following topics: introduction of Charles Darwin's revolutionary concept of a 'tree of life'; presentation of Darwin's second great idea: adaptation via Natural Selection; following The History of Life, and Human Evolution. Each week consists of 2-4 short lectures (around 15 min), reading tasks and short quizzes.

Evolutionary concept / topic / theme:

Evolutionary science in general

Content:

In this course, participants learn about evolutionary relationships, population genetics, and natural and artificial selection. Participants explore evolutionary science and learn how to integrate it into their classrooms.

Assessment

Could the activity be assessed? **Yes**

How and when to assess the activity? **Participants of the activity are assessed in the following ways:**

- **Reflection and self-assessments**
- **Multiple choice quizzes**
- **Short essays**
- **Peer feedback**

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Darwin's Sex Tape (La Sextape du Darwin), 2018

Image by Compagnie des Mers du Nord

Group of activities: **Entertaining**

Type of the activity: **Performing arts**

Country: **France**

Facilitators: **Compagnie des Mers du Nord**

Participants / target audience: **Secondary education students, university students, adults, teachers/educators**

Location: **Theatre**

Pre- knowledge: **None**

Duration: **1h30min**

Permanent activity: **No**

More information:

https://compagniedesmersdunord.fr/en/spectacles/la-sextape-de-darwin/

Short description of the activity:

A theatre show where one singer, two dancers and one actress present the diversity of sex in animals, with many references regarding evolution.

Evolutionary concept / topic / theme:

biodiversity, species, sexual selection, gender

Content:

Incredibly baroque, as improbable as amusing, here is the most delirious DIY of Evolution. An hour and a half to explore the incredible diversity of sexual behaviour and reproduction and to wonder at the narrowness of our imagination. Seeing the world through the filter of its own cultural appropriateness, Man has long considered his bipartite vision of sexuality as the norm and any other combination seemed unnatural to him. Against nature? Really? So, let's take a closer look at what nature tells us about it. An hour and a half to discover the animal world in which we live, of which we have full share. An hour and a half to celebrate what is disappearing.

Assessment

Could the activity be assessed? **Yes**

How and when to assess the activity? **Before and after the activity using a short survey**

Endless Forms: Charles Darwin, Natural Science and the Visual Arts, 2009

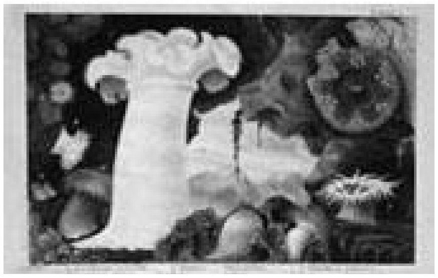

Image by Philip Gosse (1810–1888)

Studies of sea anemones and corals, c. 1858–60

Group of activities: **Entertaining**

Type of the activity: **Visual arts**

Country: **UK**

Facilitators: **No facilitators needed**

Participants / target audience: **Primary/secondary education students, university students, adults, teachers/educators**

Location: **Museum; online as virtual exhibition**

Pre- knowledge: **General knowledge about biology**

Duration: **N/A**

Permanent activity: **No**

More information:

https://britishart.yale.edu/exhibitions-programs/endless-forms-charles-darwin-natural-science-and-visual-arts

Short description of the activity:

“*The exhibition is structured thematically, with sections devoted to the importance of visual evidence for natural history, the history of the earth, the struggle for existence, the relationship of people to other animals, the relationship of people to other people, sexual selection, and the way that some late nineteenth century artists used ideas associated with Darwin*.” (Ritvo, 2009)

Evolutionary concept / topic / theme:

biodiversity, evolutionary biology, natural selection, Darwin

Content:

The exhibition explores the interchange between science and art: “*the sorts of visual imagery that filled Darwin's own mind and imagination as he formed his theories, as well as the central Darwinian themes that inspired artists - the vast age of the earth, the fierce ’struggle for existence’ that led to natural selection, and the evolution of man himself from an apelike ancestor*.” (The Fitzwilliam Museum, n.d.)

Assessment

Could the activity be assessed? **Yes**

How and when to assess the activity? **During and after the activity**

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Sex & Bugs & Rock 'n Roll

Image by Sex & Bugs & Rock 'n Roll

Group of activities: **Public events**

Type of the activity: **Science festival**

Country: **UK**

Facilitators: **Scientists**

Participants / target audience: **All age groups**

Location: **Anywhere**

Pre- knowledge: **Not required**

Duration: **Up to 1 hour**

Permanent activity: **No**

More information:

http://oro.open.ac.uk/39539/

Short description of the activity:

"*Activities such as Sex & Bugs & Rock 'n Roll demonstrate that by working with science communicators, researchers can generate and deliver entertaining public engagement activities, which stimulate research-centred dialogue. By creating relaxed, informal environments, scientists can attract diverse groups of visitors and make the research team members more approachable.* "(Sayer et al., 2014)

Evolutionary concept / topic / theme:

Evolutionary ecology, biodiversity

Content:

"*Sex & Bugs & Rock 'n Roll consisted of an eye-catching stall, hosting activities and displays related to different aspects of ecology and evolution. 'Science busks' were performed outside the stall as an effective way of drawing in passers-by. Science busks are short, interactive games and demonstrations related to specific subjects that are designed to pique people's curiosity and create a sense of fun and enjoyment."* (Sayer et al., 2014)

Assessment

Could the activity be assessed? **Yes**

How and when to assess the activity? **Possible to pre and post assess with tools.**

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Evaluating non-formal learning practices

Our previous report 'Exploratory study of evolution-themed, non-formal education in Europe' (Adnađević et al., 2020) provided insight into how evaluation of non-formal outreach activities could be improved. We confirmed a deficit related to studying the impact of evolution-themed outreach activities and their contribution to scientific literacy in evolution in particular. To measure this impact, future evaluation would need to reach beyond measuring the popularity of (i.e., number of participants) and satisfaction with an activity, towards broader questions about understanding and accepting evolution. It seems especially important to focus on how scientific literacy can be assessed and evaluated, given that this topic was only mentioned in one case during our previous investigations. However, evaluating scientific literacy is exceptionally challenging and would require a long-term study of the learning outcomes and attitude changes, rather than the more typical immediate measurements of satisfaction and perceived usefulness of activities.

We hereafter propose some suggestions to consider when designing a non-formal learning activity and considering its evaluation, focusing on answering the following questions:

- Why should we evaluate a learning activity?
- When is the time to evaluate?
- How to implement the evaluation?
- Who could be involved in the evaluation?

Why should we evaluate?

Non-formal learning activities cover a wide range of settings, situations, and actions: from exhibitions in established institutions like museums, to workshops conducted as outreach activities, to the kind of mobilising action found in Citizen Science projects – and so much more. Common to all of them is an effort to contribute, a resource to use and/or allocate, and involvement between institutions, activists, stakeholders and/or the general public. All of which, by themselves, would be valid reasons why one ought to perform an evaluation: to understand the outcome of the action and evaluate the allocation of resources.

This brings us to one of the most central aspects of evaluation: to contribute to improvement. Most non-formal learning activities are a part of larger ongoing undertakings, be they designing from scratch, revising existing activities. Even if the non-formal learning activity itself is a one-off or stand-alone activity, the stakeholders/activity-designers can still benefit from the information that can be gained through evaluations to improve related, forthcoming activities. Thus, a systemic or a structural approach is needed to ensure what is learned from one evaluation is brought further into the design and implementation of 'the next' (Fig. 1).

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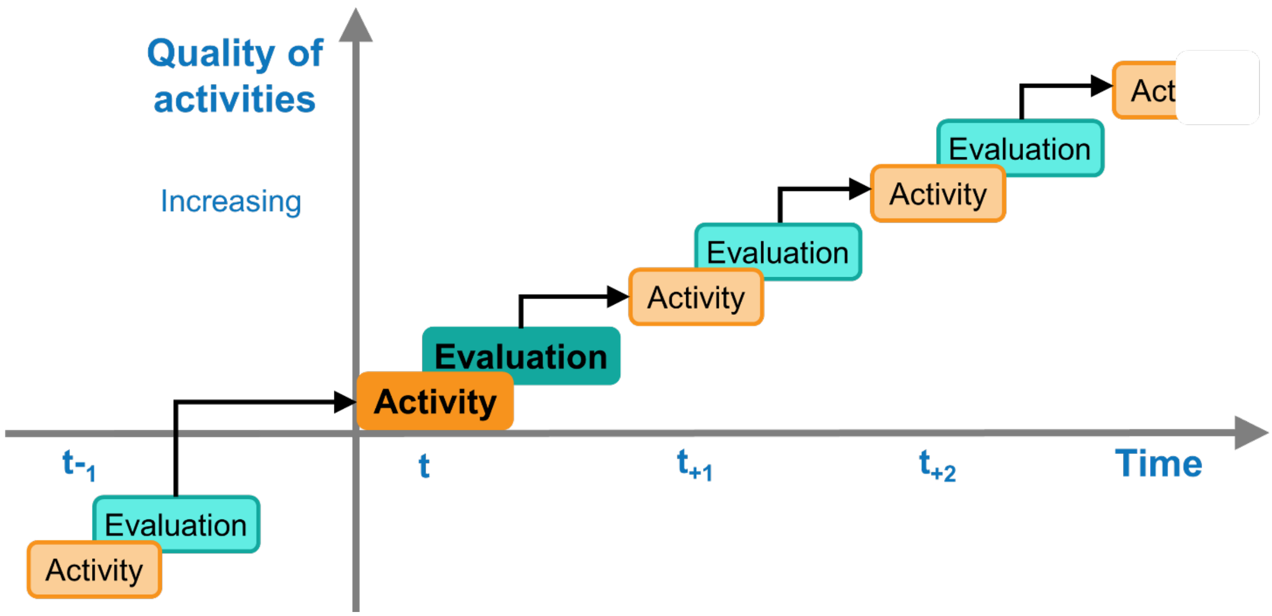

Figure 1: Improving the quality through continuous evaluation

Designing an activity at time *t* is influenced from data obtained by evaluating at t_{-1}. Evaluations done at t_1, t_2 etc. will be used to improve the design and structure of the activity at each subsequent iteration. Done in a systemic way, this ensures a gain in quality over time. For example, an evaluation can lead to revisions of the tool (the questionnaire, the interview-guide), or the observation techniques used in future activities. The findings could and do impact not just the current activity, but also future activities.

When is the time to evaluate?

Evaluation has often been a retrospective activity: Something has been done in the past, and now comes the time to evaluate if the investment in time, people and other resources has been worthwhile (economically, institutionally, etc.). Designing and conducting a non-formal learning activity is often rooted in organisational and systemic demands: since we have used (our limited) resources, did we make the best use of the resources, or could they have been better used elsewhere? (The Norwegian Ministry of Finance, 2005) This is the traditional, summative evaluation – *ex-post*, based in positivistic traditions of evaluation, often implemented as a questionnaire.

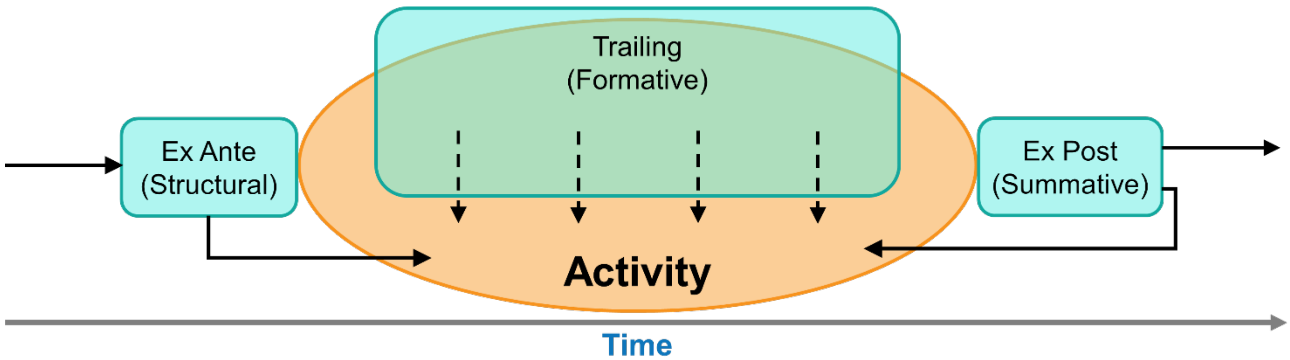

Figure 2: Typology of evaluation options in relations to the time of activity implementation

An alternative view is the prospective (Fig. 2): Evaluate to learn how one may improve (future) activities. The prospective evaluation frequently applies multiple methodologies (document studies, observations, interviews and questionnaires), and appears in two main formats:

- *Ex-ante*, that is performing an evaluation before the activity is established, with focus on designing of the process, setting of the goals, and defining the outcomes (Sollund et al., 1998). Input for evaluation is knowledge about previous experience (codified or experiential).
- Formative (trailing evaluation) evaluation parallel to and as part of the ongoing activity, where the aim is to see, to learn if/how it works and, if needed, to implement adjustments as and when required (Finne et al., 1995). A formative evaluation is an ongoing, continuing learning opportunity.

How to implement the evaluation?

There are multiple methodologies that can be used in an evaluation. Classic *ex-post* evaluation usually involves the quantitative approaches (questionnaire), and qualitative approaches (e.g. interviews) – or a mix of both, which are less frequently used. The main reason for choosing one or the other is often based on the complexity of the issue at hand. A qualitative approach is more appropriate when the activity is less structured and helps understand (rather than explains) how the activity may impact different participants' learning (Sverdrup, 2014).

If we want to evaluate clearly defined goals and outcomes, and if we want to have a high degree of control over the evaluation variables, a questionnaire may both be the preferred and the best suited choice. The questionnaire becomes less suitable in complex settings (e.g., low control over participation and the participants' degree of involvement, or lack of predefined goals and outcomes) where the more qualitative approach may be more fitting. In a nutshell, as the degree of complexity rises, the quantitative methods and predefined tools should be gradually replaced by qualitative methods (Fig. 3).

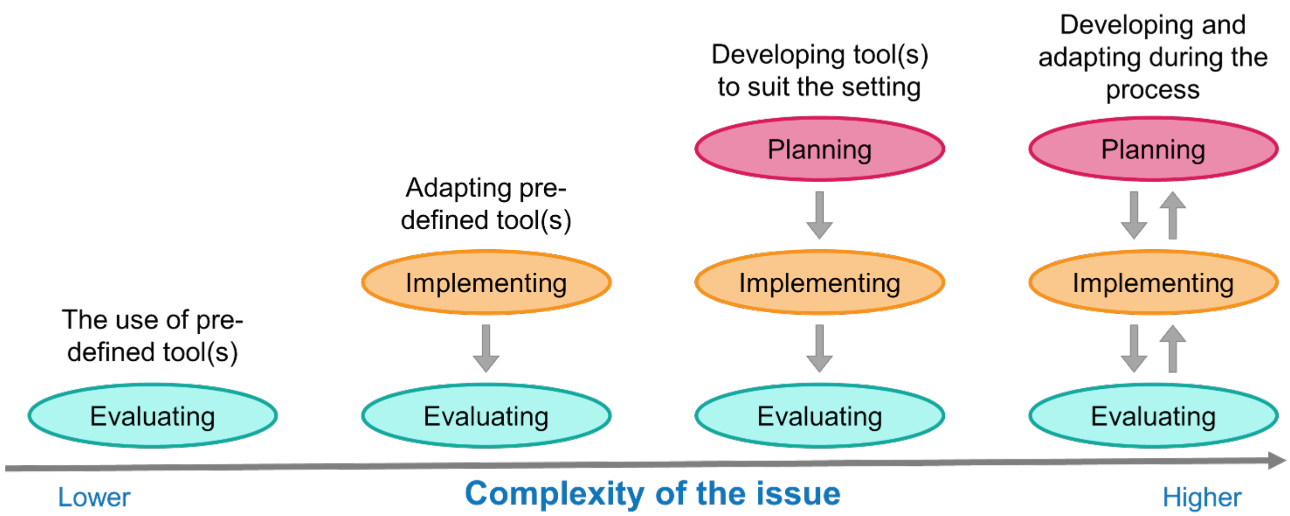

Figure 3: Adapting evaluation methodology to increasing complexity

In less complex situations, one may apply an ‘off the shelf’ validated evaluation tool, or to adapt a preferred tool. In more complex settings, there is a need to start planning ahead to ensure the evaluation design aligns with the challenges foreseen (*ex-ante* evaluation), and ultimately to make the evaluation an integrated element of the activity (trailing evaluation). This implies a transition from evaluation of a well-structured, well-known instrumental activity towards a more dynamic and flexible process with overlapping phases.

Why assess prior knowledge or skills?

Establishing predetermined standards is a necessary step in any evaluation, both to ensure an adequate measure of impact and to understand the potential impact, such as establishing a system for pre- and post-testing. Unfortunately, in non-formal learning, an activity designer, curator, or presenter, generally has no power to implement an adequate system for pre- and post-testing. Time is valuable and participants frequently do not have enough time to participate in both the activity and the evaluation (even though this could depend on the type of activity). It might be easier to establish a system for pre- and post-testing in longer-term non-formal activities, such as a citizen science project, compared to a class visit to a museum. There are strategies to combat these obstacles and succeed in conducting evaluations of non-formal learning activities e.g., through randomly selecting participants within a group, or selecting a subset of the groups to participate in the pre- and post-tests. If an activity runs over a period of time, this may provide a basis to build and evaluate against a baseline, thus enhancing the validity and enabling a better use of quantitative measures.

Who could be involved in the evaluation?

The obvious stakeholders in the evaluation process are the **participants of the activities**. They are the ones actively involved in the learning experience and they are the target of the activity. They are also the only ones that can directly tell us what they have experienced during the activity. The typical tools used to get participants' feedback are questionnaires and interviews. Individual participants or groups of participants can also be followed as they engage in the activity. This can provide useful feedback on the parts of the activity that are most interesting or most complex to grasp.

Apart from the participants, the **activity creators and implementers** are also directly involved in the process. They can use different forms of self-evaluation (through questionnaires, open-ended interviews, or reflective essays) to document their own observations after each completed activity.

If these self-evaluation tools focus on attention and involvement, and if supplemented by factual data about the participants, this data could become a valuable improvement tool for the practitioner and the institution and a way to increase the understanding of the learning ecosystem that the activity is providing to participants.

A system for quality improvement

Quality improvement is a central element in all human activities, especially when it comes to education and learning. Such a system needs to be in place to adapt to changing conditions and unstable goals – both from within, but mostly from the outside world. An often-used and applicable approach can be found in Deming's Cycles or the Plan, Do, Study, Act (PDSA) method (Fig. 4; American Society for Quality [ASQ], n.d.; Henshall, 2020; Tague, 2005)

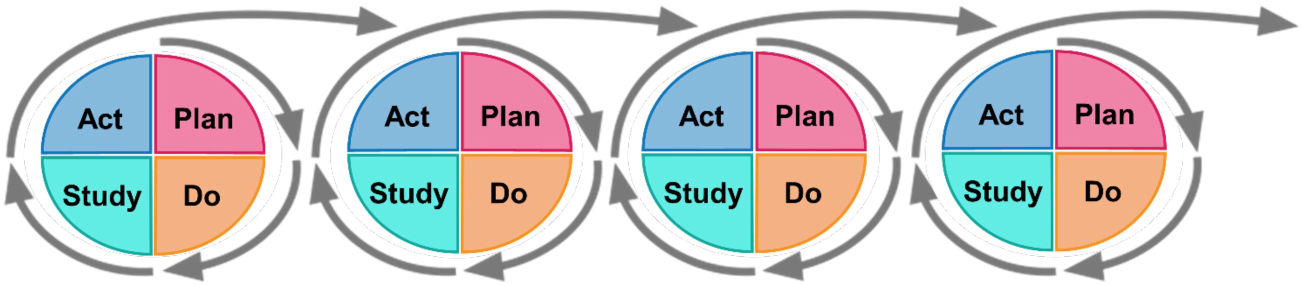

Figure 4: Deming's Cycles. 'Plan, Do, Study, Act' used in a continuous system of quality improvement. *Adapted from Henshall (2020).*

1. **Plan.** The first step is to plan ahead in order to understand what you want to – and what is possible to achieve. This partly calls for observing and estimating practical challenges, and deciding acceptable outcomes e.g., learning goals. At this stage some important questions to answer are: what problems could occur, what could be estimated or measured, and how well does the current understanding cover the issue at hand.

   Specific goals:

   - Clarify your definition/understanding of quality
   - Define 'improvement' (Since not all changes are improvements)
   - Predict potential and acceptable outcomes

2. **Do.** The second step is to actually implement the activity. While doing so, it is important to remain true to the underlying scientific principles your activities are based upon. Specify rules for how change should be understood and implemented. Design clear methodologies so that in addition to making improvements in the activity, you can explain the causal relationships between your actions/decisions and the improvements.

   Specific goals:

   - Start on the smaller scale – learn from what you do
   - Implement iterative changes both to experimental design and to formative changes
   - Maintain detailed documentation

3. **Study.** This is the third step. Deming emphasised that studying is more than an evaluation of measuring exercise. The outcomes would need to show, not only if it worked, but also why it did so. This means to venture towards understanding the issues rather than just explaining them. A system that is based upon Deming's Cycles and therefore utilises a more systemic or qualitative focus can aid in answering those questions.

Specific goals:

- Analyse if the outcomes match with the predictions.
- If not, hypothesise about what could have caused the discrepancy.
- How to examine so far unaccounted variables.

4. **Act.** Acting is both the final stage of one cycle and the first of the next. Next time around you may want to implement changes, and as you know why the effect occurs, you will be in a position to use this information. This information will also be valuable when the new activity is slightly different from the first.

   Specific goals:

   - Implement recommended changes to new designs
   - Develop a system for tracking performance data over time
   - Build capacity through documentation

Purpose of evaluations as an ongoing improvement of practice

Think about **evaluation as an ongoing process**, where the aim is less to judge what has been done and more to improve what will come. This approach is not intuitive and may require some effort to explain to other stakeholders such as departments of accountancy, human resources and public relation. While they might prioritise finding 'success stories' (or reasons to blame), we must rather focus on leveraging the occurring problems and challenges to learn how to turn them to our gain.

Additionally, conducting ongoing evaluations will not only help to design better activities, they will also help us become a better evaluator and to design and adapt tools to best suit our evaluation needs. Especially when the degree of the uncertainty increases, we need to look for approaches that are more process-oriented and more explicitly designed to fit the task at hand. A possible approach might be to start by using more qualitative evaluation techniques, like observations and interviews, in a systematic way to build knowledge and experience in context. That brings the need for the more continuous evaluation approaches – as typified through the Deming's cycles (Fig. 4).

Finally, establishing a system of dialogue and/or discussion with our colleagues might be a valuable tool to improve our processes. We are all in the same boat, and will all benefit from an exchange of hopes, challenges, experiences and (possible) setbacks.

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Evaluation as an integral part of non-formal learning activities

When considering the design of a non-formal activity, evaluation should hold an important place, as it benefits both the activity creator, as well as the participant. Evaluations give the activity creators information about what worked well and what did not. This information can then be used to improve the same activity, or as a basis for the *Ex-ante* evaluation while designing the next activity. From the participants perspective, engaging in evaluations can serve to reinforce their learning, through deliberate recall or practice.

We therefore recommend that the evaluation becomes an integral part of the activity. If possible, in addition to a big-picture evaluation of the activity, aim that different parts of the activity be evaluated individually. Increased frequency of the small, but targeted evaluation tasks within the activity can help participants stay focused on the learning objective, and direct their attention on the most important concepts, or potential misconceptions they still hold. Building these evaluations into the fabric of the activity will increase engagement in learning and make less of ‘chore’ for the participants.

Improving scientific literacy and evolution literacy means increasing not just knowledge about evolutionary concepts, but a deep understanding of evolutionary mechanisms and processes. Therefore, if we want the learning gains to be long-lasting, our focus should be on actively engaging participants in the learning process. Luckily, most non-formal educational activities are excellent strategies to actively engage audiences to think and reason about evolution. By encouraging audiences to actively participate (e.g. by presenting multiple choice questions in an online workshop, or by providing QR codes on an info-board) we can enhance the chances of having a long-term effect on improving evolution understanding and scientific literacy in a general population, and impacting the acceptance of evolution. From the activity creator’s perspective, all this engagement can be used to evaluate the activity to determine its effectiveness, as well as to support ongoing process of improvement of practice.

We know that long-term evaluation of acquired knowledge, skills, and scientific literacy can be difficult to perform, primarily because of the difficulty of tracking down the participants long after the activity takes place. However, we can be hopeful that implementing better designed activities with reinforcing evaluations will yield significant results in raising scientific literacy in the general population. Additionally, considering the diversity of non-formal learning activities and their abundance all over Europe, we are confident that they are already making and will continue to make substantial, yet unmeasurable, contributions to attitudes towards science and lifelong education of European citizens.

Wrapping it up: Working to increase evolutionary understanding and scientific literacy in Europe through non-formal learning.

The purpose of this guide was to document the examples of non-formal learning activities in Europe, to provide some theoretical insights about non-formal learning activities, and to propose guidelines (based on both published literature and our experiences) to help non-formal educators design and evaluate learning activities. The ultimate goal of this endeavour was to contribute to maximising the understanding of evolution and the development of scientific literacy, especially within Europe. We hope the guide will be useful to our fellow educators in creating new activities or improving existing ones. Additionally, we trust that new research findings will emerge through the evaluation processes of non-formal learning activities which will further the progress towards achieving our ultimate goal.

Working group 3 (WG3) of the EuroScitizen COST Action will continue to compile a non-exhaustive list of non-formal education activities from European contributors, to describe the landscape of non-formal education tackling the subject of evolution across Europe. The searchable map will be available for educators and citizens to explore at www.evodash.eu. We hope this map would offer opportunities for new Europe-wide educational partnerships to develop, between non-formal learning institutions (museums, botanical gardens, zoos, science centres), non-formal learning communities (artists, citizen scientists, DIY bio communities, teacher associations, parents, students) and citizens seeking lifelong learning.

Finally, we hope that this guide encourages, and inspires you, to continue developing exciting and effective non-formal learning activities.

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