O2 FabCitizen Pedagogical Approach and Competency Framework

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About The Fab Citizen Project

The main goal is to enable schools, in particular teachers, parents and pupils, to participate in high quality citizen science projects in both curricular and extracurricular contexts.
Citizen Science (CS) has raised a lot of attention in recent years. Its main goal is to involve citizens in different types of science projects, in particular to 1) improve engagement and 2) to increase research capacities, e.g. by shared data collection. Many projects have incorporated citizen science approaches. Whereas citizen science works well for educational purposes (e.g. in inquiry-based science education), the acceptance of CS on a scientific level ranges from low to questionable. Even though the European Association for Citizen Science has clear guidelines and support mechanisms, many CS projects are not taken seriously. This was the main starting point for the FabCitizen project: We provide tools to increase the quality of CS projects, in particular in schools. For this purpose, we integrate FabLabs as the main educational environment as they can provide both technological as well as methodological expertise.
We base our project on clearly defined requirements, amongst them:

- In schools, CS projects need to be embedded into the curriculum in various subjects
- To ease the implementation, teachers need high quality (open) scenarios and learning materials
- CS projects need support in terms of methodological and technological expertise.

In the project, we achieved the following main results:

- A Citizen Science competency framework describing knowledge, skills and attitudes to successfully engage in high quality CS projects
- A pedagogical concept incorporating aspects of service learning
- A guide for FabLabs as the key infrastructure to educate and train citizens.
- More than 150 Open learning scenarios to train teachers, pupils and parents in early secondary school
- A collection of Open Educational Resources supporting the approach
- A good practice guide for schools and FabLabs across Europe

The project provides guidance and concrete support to universities, FabLabs, schools and the surrounding communities to participate in successful, high quality CS projects.

0 Introduction

Citizen Science (CS) has raised a lot of attention in the last years. Its main goal is to involve citizens in different types of science projects, in particular to 1) improve engagement, 2) to increase research capacities, e.g. by shared data collection and 3) use as an educational tool, in particular in the STEM field. However, there are many challenges regarding individual competencies and skills mismatches. For example, lack of technological or methodological skills of the participants, data handling (e.g. collection, analysis and interpretation, critical reflection) is a specialists' skill, hesistance of teachers to incorporate CS due to the lack of skills and lack of awareness on what Citizen Science is.

This is the main starting point for the FabCitizen project: We aim at providing tools to increase the quality of CS projects, in particular in schools. We focus on an educational perspective since CS provides many added values to STEM education (Perello et al, 2017, Nistor et al, 2019, Shah & Martinez, 2016). More specifically CS can improve STEM related learning outcomes, increase motivation and engagement but also incorporate environmental responsibility or engaged citizenship as well as data analysis and collection (Mandinach & Gummer,2013; Wolf et al, 2016). The combination of Citizen Science and data literacy is of particular interest to us. As many studies have discussed the synergies of those two concepts (Sagy et al 2019, Twidale et al, 2013), surprisingly few CS frameworks specifically focus on data.

The report presents FabCitizen Pedagogical and Competency frameworks for CS focused on grades 5-9 including the links to existing curricula which in many cases do not cover citizen science / data literacy.

- **Pedagogical Framework** (Section 2) describes the pedagogical and didactic assumptions and principles for Citizen Science application in schools. The framework elaborates on three main factors influencing the way learning activities should be designed (1) inquiry-based learning, (2) service learning corresponding to social needs, and (3) physical context of application. Special attention is given to the FabLab's as physical facilities since they combine technological knowledge about emerging technologies, methodological knowledge on critical topics (e.g. data science) and the use of innovative teaching and engagement methods.
- **Competency Framework** (Section 3) outlining the curriculum for CS in schools (grades 5-9). The framework is designed based on literature review and different existing curricula. The initial result will be a list of core competencies as candidates for the curriculum. As the second phase, we will prioritize competences – those priorities will lead to a first version of the curriculum which can be seen as a harmonized curriculum including curricula and experiences across Europe. Finally, we will also provide a competence framework for teacher trainers. This will be derived from the competence framework for schools.
- **Competency Scheme** (Section 4) presents guidelines on how to map curricula to the competence framework in other countries than the participating. The competency

description scheme will be used to achieve a harmonized description for the different European curricula taken into account. The standardized scheme (description format) will be accompanied by the most important part, the guideline how to map other curricula and CS curriculum. By this, we want to contribute towards European harmonization of curricula.

- **Competency Mapping** (Section 4). It cannot be expected that many European curricula will be changed within the project duration. Therefore, the section provides guidance on how to incorporate CS into teaching without changing curricula. To achieve this, the CS curriculum was mapped to other subjects (such as mathematics, languages, arts, social studies). This ensures that teachers can easily include selected competences without changing curricula.

In development of the frameworks, an iterative approach was applied. The initial version of artifacts is constructed/designed based on literature reviews. The next two iterations of the artifacts are influenced by the user feedback gathered in focus groups, pilots and large scale trials.

1 Theoretical Frameworks

The FabCitizen Pedagocical Framework and Competency Frameworks come as a result of theoretical influences of three research streams:

- **Inquiry-based learning** is the main process element and pedagogical approach of the model which students follow methods and practices similar to those of professional scientists in order to construct knowledge;
- **Service Learning** is understood as the outcome of CS process where the community should be 1) involved and 2) benefit from citizen science projects;
- **Learning environment**, especially FabLabs are understood as the context of implementation and the main meeting hub for citizen science projects.

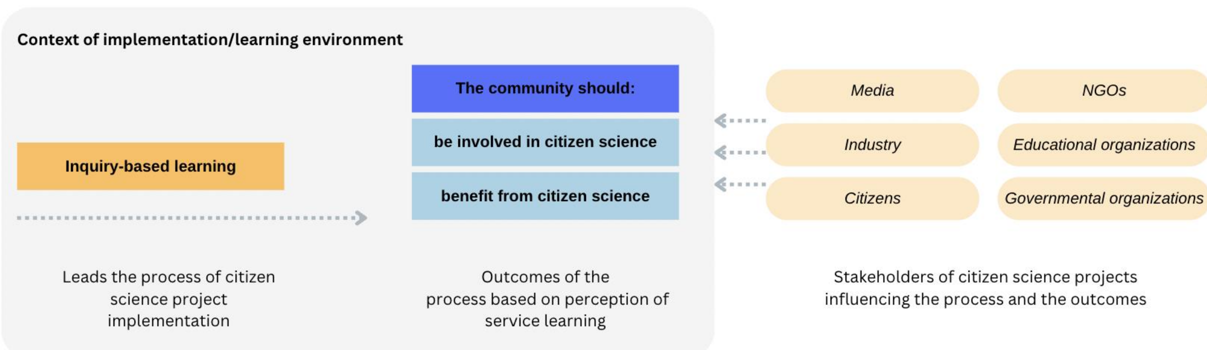


Figure 1: FabCitizen Pedagogical Model

Following sections discuss these three research streams and outline their connections to Citizen Science application in the context of education.

1.1 Inquiry-based Learning

Definition	Inquiry based learning
	"Inquiry-based learning is an educational strategy in which students follow methods and practices similar to those of professional scientists in order to construct knowledge" (Keselman, 2003, cited by Pedaste et al., 2015, p. 48).

The aim of inquiry-based learning is to involve the students in the scientific discovery process. Therefore, smaller units called 'inquiry phases' are created on the basis of the scientific process (Pedaste et al., 2015) and several 'inquiry phases' are used to form a scientific process. According Pedaste et al. (2015) inquiry-based learning should go through following phases:

- **Orientation**. The process of stimulating curiosity about a topic and addressing a learning challenge through a problem statement.

- **Conceptualization**. The process of stating theory-based questions and/or hypotheses. Two sub-phases can be defined: (1) Conceptualization i.e. the process of generating research questions based on the stated problem and (2) Hypothesis Generation i.e. the process of generating hypotheses regarding the stated problem.
- **Investigation**. The process of planning exploration or experimentation, collecting and analyzing data based on the experimental design or exploration. Three sub-phases can be defined: (1) Exploration i.e. the process of systematic and planned data generation based on a research question; (2) Experimentation i.e. the process of designing and conducting an experiment to test a hypothesis; and (3) Data Interpretation i.e. the process of making meaning out of collected data and synthesizing new knowledge.
- **Conclusion**. The process of drawing conclusions from the data. Comparing inferences made based on data with hypotheses or research questions.
- **Discussion**. The process of presenting findings of phases or the whole inquiry cycle by communicating with others and/or controlling the whole learning process or its phases by engaging in reflective activities. Two sub-phases can be defined: (1) Communication i.e. the process of presenting outcomes of an inquiry phase or of the whole inquiry cycle to others (peers, teachers) and collecting feedback from them. Discussion with others; and (2) Reflection i.e. the process of describing, critiquing, evaluating, and discussing the whole inquiry cycle or a specific phase.

CS and inquiry-based learning are closely linked, as inquiry-based learning is used as a didactic teaching method in many CS projects (Raddick et al., 2009; Sharples et al., 2017). Jenkins (2011) pointed out some positive effects of inquiry-based learning within CS projects.In addition, both concepts are summarized under the term ‘citizen inquiry’. There are also some platforms and webtools (e.g. nQuire) (Herodotou et al., 2018) that are used to support citizen inquiry (i.e. both online CS projects and inquiry-based learning approaches).

1.2 Service Learning

Definition	Service Learning (SL)
	Form of experiential education which integrates meaningful community service into a learning environment.

According to Preradovic (2015) service learning understanding can be divided into two groups: (1) SL as a form of education; and (2) SL as an educational philosophy. In this review, we will focus on the first one. Service Learning in this frame of understanding, is closely related to student volunteerism. However, some noticeable differences exist. According to Eyler & Giles (1999), in SL both the student and the community are equal and direct beneficiaries. There is a growing body of research into SL as a transformative pedagogy approach for the students (Mergler et al. 2017).

Service-Learning stands out as a form of teaching which connects theory and practice by giving students the opportunity both to participate in an organized service activity that meets community needs and to reflect on the experience in class in order to gain a deeper understanding of the course content and an enhanced sense of civic engagement (Bringle, Hatcher & McIntosh, 2006). From this definition, SL can be interpreted based on three essential elements: service, learning and reflection. This means that learning does not necessarily occur as a result of learning experience but as a result of reflective components explicitly designed to foster learning (Jacoby, 2014).

Chamber & Lavery (2017) four type activities attributed to SL: a direct service for people in need, an indirect service for broader issues in the community without personal contact to people in need, advocacy for people in need or community-based research. Here, it's where the connection between Citizen Science and Service Science can be seen most clearly. Some CS communities already offer student possibilities to fulfill their service hour requirement through their platforms. One notable example is Zooniverse (Zooniverse, 2021). Some other research-based examples of service learning include: (1) Writing a guide on available community services and translating it into Spanish and other language; (2) Conducting longitudinal studies of local bodies of water; water testing for local residents; (3) Gathering information and creating brochures or videos for non-profit agencies; and (4) Mapping state lands and monitoring flora and fauna (FSCJ Center for Civic Engagement, 2021). Up until recently, SL was mostly related to offline activities of students in their immediate communities. However, technological development has brought SL closer to digital technologies and most importantly digital communities.

According to the US-based National Youth Leadership Council (2008), all forms of Service-Learning should meet certain quality criteria, in particular with regard to the meaningfulness of the service, link to the curriculum, reflection, partnerships and diversity. This means if we incorporate Service Learning in developing learning scenarios during project duration - partnerships with research-based institutions or local communities have to be established. Another element that needs in-depth considerations is the reflection part of the projects. SL is often critiqued because of its strong emphasis on reflection in evaluation of students. Clayton et al. (2013) state that reflection is hard to assess and complicates evaluation process.

1.3 FabLabs as the Learning Environment

Definition	FabLabs (Fabrication Laboratory)
	Small-scale workshops that offer digital fabrication and rapid prototyping opportunities to the public, providing digital tools and machines to anyone interested in developing original ideas to solve problems

FabLabs are open and inclusive co-creation spaces, sharing not only tools and materials, but also knowledge, experiences, and ideas. These spaces are generally equipped with the necessary tools for digital and physical fabrication, including computers, 3D printers, plotters, laser engraving and cutting machines, vinyl cutters, CNC mill, welding, mechatronics hardware, and woodworking (Bisballe - et al, 2016).

FabLabs are not just physical places, but also meeting centers for makers, fabbers and any kind of participants to co-learn, collaborate and co-create (Weber - Khademian, 2008). This mindset of FabLab has contributed to create the open and community-based maker culture of today. FabLabs are accessible makerspaces that have a “common-based peer production approach” (Troxler - Wolf, 2010) which was developed based on Neil Gershenfeld’s "How to do (almost) anything" lecture (Gershenfeld, 2005), and this occurs not only in community settings, but also in educational scenarios where FabLabs have been used to encourage students and teachers to become creators, doers and innovators in areas of Science, Technology, Engineering, and Mathematics (STEM) (Blikstein - Kabayadondo, 2017).

Relation to Citizen Science as a learning mean

The contribution of FabLabs and makerspaces is studied in the literature mainly for primary and secondary education, (Irie - Hsu, 2019) but also for tertiary education. In various articles, Dale Dougherty presents an important aspect of the dynamic that FabLabs and makerspaces contribute to, which he calls the maker mindset. FabLabs have a particular potential in STEM Education, given that students who participate in these settings “implement scientific knowledge while gaining relevant technical skills and developing the art of creative thought” (Stephenson - Dow, 2014). These spaces expand the opportunity to transform educational paradigms as they promote the maker culture, challenging traditional models of teaching and learning.

FabLabs promote an active learning process in which students are at the center of the educational process as they act as protagonists doing meaningful activities that promote critical thinking (Menéndez, Guevara, 2019). As a result, FabLabs become spaces that endorse a holistic learning, offering insights into the kinds of caring actions, communications and dialogues that are at the center of a space that redress the bifurcation of cognition and emotion in education (Fernández - Cárdenas, 2014). As a consequence, FabLabs usually center educational processes in students, instead of focusing on teachers, because they offer “youth substantial say in what and how they make” (Martin, 2015).

The increasing digitalization and automation of industrial processes results that in the future companies will need even better trained specialists in these fields. Traditional learning and teaching methods are reaching their limits. In this regard numerous studies demonstrate that hand-on training is beneficial for students (Sorko - Irsa, 2019).

The educational value of Apprenticeships in Fablabs

Apprenticeship is a training and employment system designed to prepare individuals for future employment, employability and active citizenship. Apprenticeships can also enable professionals to obtain a license to practice a regulated profession. Most training takes place while working for an employer who helps apprentices learn their trade or profession in exchange for their continued employment for an agreed period after they have attained measurable skills. Throughout the world, apprenticeship is considered an important and powerful way to develop a high-quality workforce, but there is no global consensus on a single term for apprenticeship: depending on the country and sector, the same or similar definitions are used to describe the terms apprenticeship, internship and traineeship. Apprenticeship is the term preferred by the European Commission and the one chosen for use by the European Centre for the Development of Vocational Training (CEDEFOP), which has developed many studies on the subject. (Wikipedia)

As seen, FabLabs are collaborative workspaces for learning, exploring and sharing, an ideal environment for an apprenticeship. They can be a meeting point for tools, people, projects and skills. Moreover, activities in FabLabs are often related to personal development and self-regulation, and foster knowledge production instead of knowledge consumption. It is not surprising that FabLabs are proliferating in formal education, from primary to vocational education and training (VET). FabLabs can offer access to high or low-tech equipment and a community of committed makers who can provide the 'know-how' (Dougherty, 2016). The processes of creation and invention usually also involve problem solving and immersion in personally meaningful projects (Sheridan et al., 2014).

There are three aspects of FabLabs that make them particularly interesting for the education and training sector. Firstly, it is their interdisciplinary aspect and, secondly, the fact that by exploring and focusing on solving authentic real-world problems, individuals acquire new knowledge and create meaning from this experience. Thirdly, FabLabs are known for their flexible learning modes that can range from peer learning, peer mentoring, peer coaching and peer teaching to more structured demonstrations of tools in the lab. This blending of traditional and digital skills, arts and engineering creates a learning environment in which there are multiple entry points to participation and leads to innovative combinations, juxtapositions, and uses of disciplinary knowledge and skill. In the same study, authors frequently observed “people working in one [disciplinary] area, watching someone in another, and drifting over to get involved [in another disciplinary area] (Sheridan et al., 2014).

Formal education and training according to the International Standard Classification of Education 2011 (ISCED, 2011) is defined as “education that is institutionalized, intentional and planned through public organizations and recognised private bodies”. Vocational education is often recognised as being part of the formal education system. Curriculum planning and the design of education programmes and qualification requirements is a way to integrate makerspaces, and making activities into learning activities within compulsory education, Vocational Education and Training and in Higher Education. In this context, a number of EU Member States have added topics such as coding, programming and computational thinking into school curricula (JRC, 201630, Eurydice, 2019).

Since the declining youth cohorts, municipalities decided to start using the makerspace for the Vocational Education and Training school to empower all-age learning. FabLabs lies at the heart of this re-skilling strategy: all types of machinery, tools and resources are already there, and thanks to the versatility of the learning arrangements (e.g. peer-learning and teaching, mingling with experts and learning skills directly from them), there is no longer need for structured courses. This new apprenticeship model was recently certified and it is starting to show results in getting people to employment, at least for short-term jobs.

Fablabs: a promising future

“*Fablabs are exciting new learning environments, and fabbers experience learning in all the depicted dimensions all the time without thinking about being ‘educated’. If we want to ensure that complex and sustainable learning can happen for more people, bridging the social and digital divide, beyond just addressing those who pos- sess self-motivation, we have to think about possible changes in conditions and arrangements*” (Schelhowe, 2013).

As the quote indicates, Schelhowe supports the idea that FabLabs are "new and exciting learning environments." The article also emphasizes "from a general and theoretical point of view the very unique and original advantage that FabLabs - with their not-so-cheap infrastructure - can offer over other educational environments, as well as the fact that skills can be trained while students are having fun."

"*Human beings learn all the time and everywhere*" Heidi Schelhowe further argues in her article "Digital Realities, Physical Action and Deep Learning." FabLabs are also places where people continue to learn. According to her, physical action is an important aspect of the learning process. Referring to many scholars in the education’s field, she believes that there is a close interconnection between physical activity and mental understanding for learning.

Learning in FabLabs is not like the traditional classroom experience, but rather a place for experiment and new ideas which come from the learner him/herself. FabLabs are now where people of all ages can make needed things, that are fun and which are useful for the community. Based on these considerations, Heidi Schelhowe has listed five good reasons to develop FabLabs as high-potential learning environments (Schelhowe, 2013). Those are:

1. *Combining physical activity and abstract thinking*: For learning purposes, the facilitators have to make sure that both the abstract design and the actual production of a physical object are important for the learning process, which is enabled by technology.
2. *Revealing the model behind the scene*: It is important to go beyond just using technology in a FabLab to create objects, and actually understand the principles and the steps of the whole process.
3. *Initiating processes of reinventing and refining one's own ideas and products*: Part of the learning experience is to make sure that there’s always an inspirational environment, where students are motivated to experiment and create something new.

4. *Relating to post-modern society's conditions*: FabLabs have the possibility to bring challenges and questions of our era to the classroom, thus making the learning experience closer to life outside the school. This helps students to understand the world and our place in it.
5. *Social and community learning*: Collaboration and integration are inherent aspects of working in a FabLab. This makes the students more open to new ideas and doing projects together.

Digital fabrication and "making," and the positive social movement around them, could be an unprecedented opportunity for educators to advance a progressive educational agenda in which project- based, interest-driven, student-centered learning are at the centerstage of students' educational experiences (Bilkstein & Krannich 2013).

There are nowadays different approaches to educational concepts in various school curricula. Most schools have small in-house labs (science, chemistry, technology, art, etc.) in fact little used by students and teachers, some still tied to a traditional classroom learning model or not encouraged to use labs due to lack of proper resources to update them. It would therefore be wishful to aim for a different organization of the school model that considers fablabs as the main learning environment able to catalyze the human and economic resources of schools belonging to the target user base. In this scenario, Fablabs have a great potential for impacting education and can play an important role in education by offering various forms of support, as well as a means to make projects become more than digitaldata. FabLabs can also be a bridge between academic learning and practical learning that results in new products and new solutions for the community (Dilnesaw et al., 2013).

Fablabs in Metaverse, an extension of a learning environment in virtual spaces

The Internet is a place, albeit virtual, where the greatest amount of information resides, within everyone's reach. This makes it an excellent teaching tool, nowadays used by an increasing number of education centers, universities and private companies, in order to convey new knowledge. According to Duan et al. (2021), the most recent version of the Internet is the Metaverse. Meta is Greek for beyond, and verse represents the totality of something. In this way, the Metaverse alters the human experience, using technology to go beyond our physical reality (Pimentel et al., 2022). The term was originally coined by science fiction author Neal Stephenson in his 1992 novel "Snow Crash"; in it, he describes the Metaverse as a virtual world composed of unique environments, each with a specific purpose: to entertain, socialize, educate, and more (Stephenson, 2000).

Due to the quarantine of COVID-19, the metaverse has provided the ability to run off physical time and space limitations, using non-face-to-face services (Kim, 2021). As face-to-face communication becomes difficult due to COVID-19, activities that were thought to be only possible offline are being converted to virtual reality and are rapidly expanding into various fields such as education, medical care, fashion, and tourism. The metaverse can be used successfully by E-Learning as a solution for the subjects that depend totally on convergence and cannot be taught online or in distance learning. Metaverse-based systems can also be used to provide safe and efficient environments for education and business by applying virtual reality technologies and continuously studying and endeavoring to expand learning experiences (Jeon, 2021). In addition, the metaverse is not just a virtual reality environment, but it also merges the Internet and web technologies. The metaverse is attracting attention as an alternative to overcome the limitations of existing 2D-based online and remote classes. It can provide a differentiated experience value from the current internet era due to the complex use of various technologies. Furthermore, the metaverse makes it possible to design a new experience that transcends time and space. Metaverse-based education enables the use of infinite space and data and has the advantage of allowing interaction at the level of face-to-face education (Lee, 2021).

A compendium of existing educational applications has been published by the 'Virtual Human Interaction LAB' of Stanford University, VR Education Applications | VHIL (stanfordvr.com). In addition, information and articles on the subject of education in virtually reconstructed environments can be found there.

In the light of this evidence, the hypothesis is to propose the Metaverse as a further area of experimentation, going backwards along the road taken by Niel Gershenfeld, or in other words, closing the circle that leads from the BIT to the atom by returning to the BIT again, transducing the material environment of a digital fabrication laboratory into its virtual counterpart of a FabLab, the ideal place to propose training contents relating to digital fabrication technologies.

2 FabCitizen Pedagogical Framework

The theoretical considerations outlined in Section 1 emphasize the need for designing a framework providing guidance on implementation of CS projects in schools. Hence, the following section guides us through the design of the Pedagogical Framework fo Citizen Science application which consists of two parts: principles of design and process phases.

2.1 Process of the Pedagogical Framework Design

The design of the Pedagogical Framework was implemented by completing five tasks (See Figure 2 below).

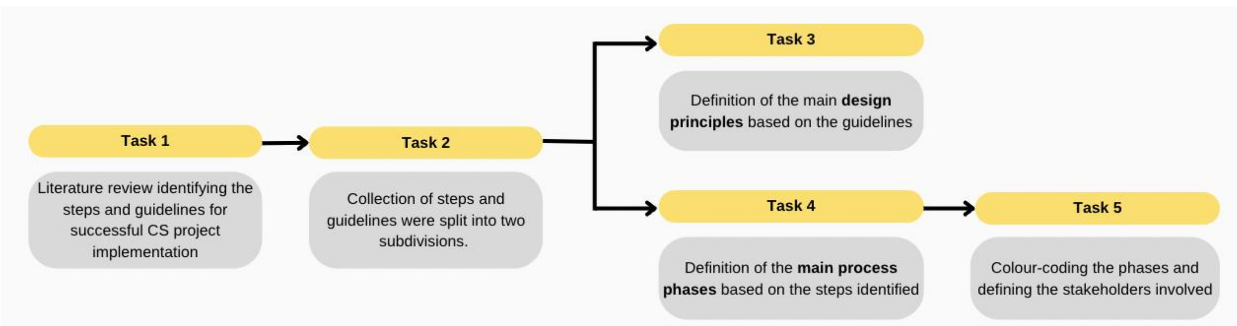


Figure 2: The process of defining the competency-based Pedagogical Framework

The initial task of the design process was the **literature review** of the instructions, guidelines, instructions and principles for the implementation of CS projects in schools. The goal of the literature review was to identify the main steps and guidelines of successful CS project implementation. In this context, we defined:

- **Steps** as a processes that have to be executed concretely and have a defined beginning and end (e.g. 'conduct a project meeting').
- **Guidelines** as instructions that apply and/or have to be followed over the entire project period or part of the project period (e.g. 'communicate effectively').

It is important to note, that some aspects can be both a guideline and a step, depending on the perspective from which they are viewed. An example of this is: 'Pupils can do different tasks in projects and choose them according to their interests’. For pupils it is a step, since it is an executable action, whereas it is a guideline for researchers.

The collection of steps and guidelines was later split into two subdivisions. The subdivision of guidelines allowed to defined the main design principles of the Pedagogical Framework (presented in Section 1.3.1). The subdivision of steps formed the basis for the definition of five-phase-process in the Pedagogical Framework (presented in Section 1.3.2). Finally, collection of design principles and process phases were summarized as a process map. In addition, the steps were colour-coded to indicate the school-specific, competency-based and standard processes.

2.2 Process of Citizen Science Project Implementation in Schools

The tasks defined in Section 2.1 allowed to map out the generic process map of Citizen Science implementation in schools (See Figure 23 below). The basis of the model are the structures put forward by Bonney et al. (2009) and Shirk et al. (2012). The process map is colour coded i.e. turquoise refers to the school-specific processes that have been adapted to the context of the school, light-blue refers to standard processes and green refers to the competency-oriented processes. In addition the model represents the involvement of the stakeholders (i.e. the community, researchers, teachers, students and parents) in each step. The focus is given to the involvement of the school rather than of the community, as the methodology is developed for the educational sector.

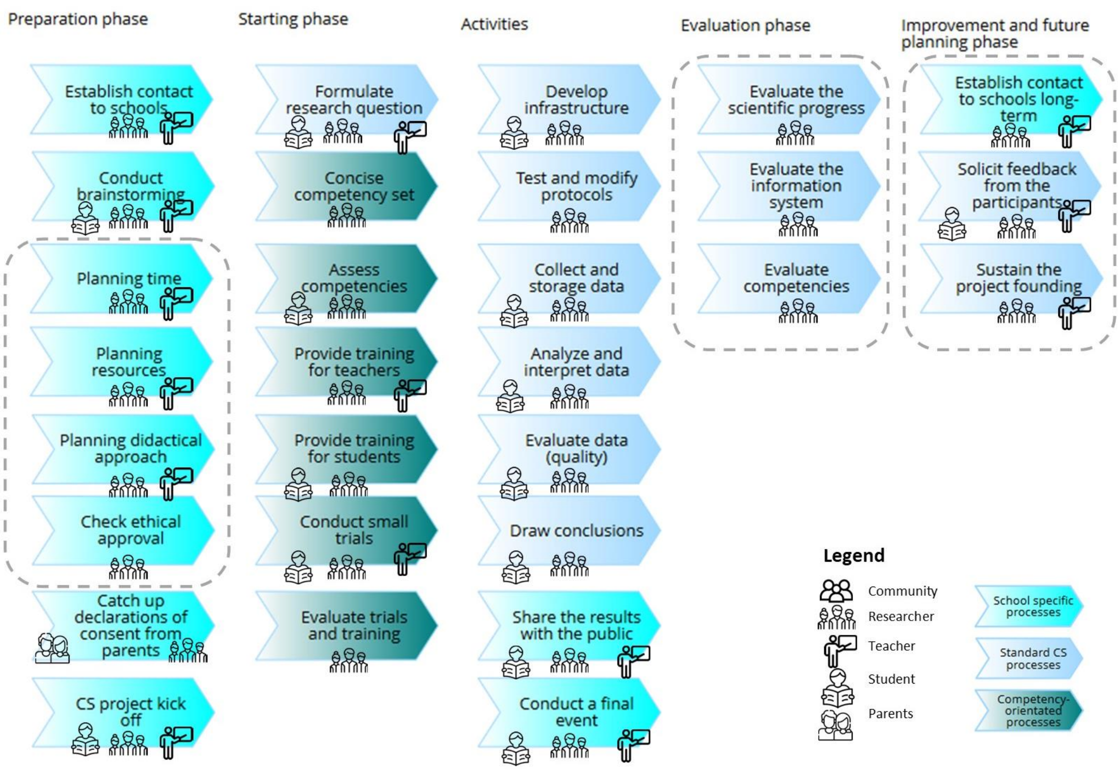


Figure 3: Generic competency-based methodology for educational Citizen Science projects

The process represents the temporal component to some extent. First, it runs from right to left (oriented at the project phases) and within the project phases from above down runs off. Since some processes can also run in parallel, this is marked by dashed lines. The dashed lines make it clear that the order of the processes within them can be interchanged. Following phases and sub-steps form the basis of the model.

Phase 1	Preparation

The preparation phase encompasses the activities which need to be performed in advance of the project in order to ensure the enabling environment:

- Establishing the contact with the schools. To establish the connection to schools, it is useful to come to the schools before the project planning is started (OEAD, 2021). This enables getting to know each other and gives teachers the opportunity to gain an initial understanding of CS projects.
- Conducting the brainstorming. In the brainstorming phase, topics for CS projects can be discussed. Since participatory CS projects should consider scientific and student interests (Senabre Hidalgo et al., 2021), it is important to undertake steps to integrate both interests into the model; however balancing the interests of students and researchers is a challenge (Kloetzer et al., 2021). To find new topics for CS in IS or to identify topics of interest, it is valuable to ask teachers and students about their interests. Brainstorming sessions are recommended for this purpose, which reflect the perspective of the researchers and can incorporate the experience from research.
- Time planning is necessary because schools and universities have different timetables, one must be aware of both timetables, including overlaps and specific aspects. University includes lecture-free and exam-intensive periods, whereas schools have autonomous days and exam-intensive periods at different times. Moreover, one recommendation is to conduct project planning meetings with schools in May and June because this is when the planning occurs for the next school year. In addition, time planning includes finding free space in lesson series or considers the implementation of project days. Concerning the integration of CS projects into the curricula, elective subjects or free hours for project work in the curricula plan can be used. (OEAD, 2021)
- Resource planning includes financial, personnel and spatial aspects. A first step is to conduct a cost analysis and funding and to plan material, spatial and personnel resources (OEAD, 2021; Tweddle et al., 2012; U.S. GSA, 2021; Yadav & Darlington, 2017).
- Planning didactical and fit to the curricula. Since the connection to the curricula is a challenge of CS in formal education (Kloetzer et al., 2021), it is useful to provide a fit between the curricula and the trained and learned competencies in the CS project. The competency set based on Nowak et al. (2021) was used as input for the methodology. As described later in *Chapter 5.2*, the competency upper categories were reduced from 83 of Nowak et al. (2021) to seven containing nine sub-upper categories. This step facilitated mapping the school curricula and overcoming the barrier ‘connection to the curricula’.
- Ensuring the ethics approval. Before starting the project, it needs to be checked whether an ethical approval from the directorate of education is needed. Furthermore, questions about the assurance of the guiding project staff and the participants should be answered. (OEAD, 2021)
- Consent from parents. For undertaking CS projects at schools, declarations of consent for participation are needed from the parents (OEAD, 2021) as well as photo consent forms.
- CS project kick-off and initial narrowing down of the topics are followed by further planning for integration into the lessons and for the didactic concept and process. Furthermore, the kick-off also forms a team consisting of scientists, educators, evaluators and leaders (Bonney, Cooper et al., 2009; Harris & Ballard, 2018; Tweddle et al., 2012).

Phase 2	Starting

The starting phase encompasses the actions aimed at design of the research methodology, teacher training and definition of competencies. More specifically the actions include:

- Formulation of the research question(s). To follow the steps of the scientific inquiry circle, one first defines a question or issue that is of interest to students and researchers (Bonney, Cooper et al., 2009; Harris & Ballard, 2018; Heigl et al., 2020; Shirk et al., 2012). It is important that the research question fits the planned CS design and is suitable for a CS approach (Pocock et al., 2013).
- Concise competency set. One step is to revise the set of competencies to train appropriate competencies for the CS projects. The set is adapted to which competencies are necessary to execute the CS project for pupils and teachers. The extent to which pupils are involved in the phases of the scientific inquiry circle was determined during the didactic planning beforehand.
- Assessing the competencies. To assess competencies and initially determine the competencies of students and teachers, they both conduct self-assessments of competencies of the above-mentioned set to get to know the skill level of participants (U.S. GSA, 2021). In the case of strong competency gaps, special focus is placed on this step in the training (Pocock et al., 2013; Tweddle et al., 2012).
- Providing the training for teachers and students. Sample learning scenarios examples are provided to undertake CS training. Furthermore, the structure of the learning scenarios serves as a template for developing new learning scenarios and is based on Nikolov, Shoikova, and Kovatcheva (2014) and can be found in *Appendix 3: Learning scenario template orientated on Nikolov et* al. (2014). The training can be developed based on these learning scenarios to teach competencies from the specified competency set. Teachers and students receive joint training from researchers.
- Conducting small trials. To gain initial experience with school groups, it is helpful to first conduct small trials to gain more experience, which can be used to further develop the competency-based method for the school context (Tweddle et al., 2012).
- Evaluating the trials and training. One step is to revise the set of competencies to train appropriate competencies for the CS projects. Based on the revised competency set, the next steps, providing training for teachers and students, will be conducted (Tweddle et al., 2012). The training is tailored to the previously defined set of competencies so that both teachers and students will gain the necessary competencies to successfully implement the CS project. To review and monitor the success of the training and, the training will be evaluated (e.g., using a self-assessment form).

Phase 3	Activities

After initial preparations, the actual implementation of Citizen Science activities involves the following steps:

- Developing the infrastructure. The first step is to develop and provide infrastructure, where IT support is important to implement the project since some schools lack Wi-Fi, tablets or other hardware (Nowak et al., 2021). As an orientation for the deployment of the CS application, the categorisation framework from Yadav and Darlington (2017) can be used, including the deployment process . The infrastructure must fit the data to be collected (Herodotou et al., 2018; U.S. GSA, 2021). Possibilities of infrastructure are, for example, a mobile application to scaffold data collection or the deployment of a thin or thick client or to perform sensor data processing (Yadav & Darlington, 2017).
- Testing and modifying the protocols. Protocols for collecting data should be tested and modified (Pocock et al., 2013; Tweddle et al., 2012).
- Collecting and storing the data. The data then need to be collected and accepted, edited and displayed in a further step (Bonney, Cooper et al., 2009; Tweddle et al., 2012). Furthermore, data is stored safely (U.S. GSA, 2021).
- Analyzing and interpreting the data. To gain further insights about the data, they are analyzed and interpreted (Bonney, Cooper et al., 2009; Harris & Ballard, 2018; U.S. GSA, 2021; Yadav & Darlington, 2017). Furthermore, the data is visualized (Tweddle et al., 2012).
- Evaluating the data quality. Because many CS projects lack data quality (Lukyanenko et al., 2016), evaluating data is an important step. Furthermore, data quality can be evaluated in relation to several dimensions (e.g., completeness, accuracy, consistency) (Mäkipää et al., 2020).
- Drawing conclusions. Findings are then drawn from the collected and analyzed data. For this purpose the data can be visualized (Tweddle et al., 2012). In addition, the research question posed at the beginning should be addressed and an answer provided (European Citizen Science Association & others, 2015).
- Sharing the results with the public. Data can then be shared, uploaded and be made publicly available (European Citizen Science Association & others, 2015; Harris & Ballard, 2018; Heigl et al., 2020; U.S. GSA, 2021). The results should be disseminated and finally published with open access (Bonney, Cooper et al., 2009; Heigl et al., 2020; Tweddle et al., 2012; U.S. GSA, 2021).
- Conducting the final event. Furthermore, the results of the CS project can be presented at a school in the context of a final event or presentation in class (Harris & Ballard, 2018). At this point, one could also examine the possibility of submitting the results in the context of competitions, such as ‘Youth research’s and thus an additional final and appreciative event can take place.

Phase 4	Activities

In the fourth step, the outcomes should be evaluated according to the evaluation framework of Kieslinger et al. (2018). The outcomes are threefold and orientated based on the model for public participation in research of Shirk et al. (2012):

- Advancement in the scientific progress. The outcomes for science could be achieved through the investigations of citizen scientists in a subject area. This encompasses improved scientific understanding, as well as scientific publications and large-scale projects (Shirk et al., 2012).
- Social-ecological outcomes. With regard to social-ecological systems, outcomes can be "improved relationships between communities and management agencies (Tudor and Dvornich 2001, Ballard et al. 2008), backyard enhancement of wildlife habitat (Evans et al. 2005), access to and use of data to address environmental degradation (Overdevest and Mayer 2008), and increased likelihood of participant engagement in policy processes to improve their surroundings (Overdevest et al. 2004, Wilderman et al. 2004a)" cited from Shirk et al., 2012, p. 9).
- Competencies. To review and monitor the success of the CS project, the teachers and students perform a self-assessment of their competencies after the project. The competencies for evaluation can be taken from the adapted competency framework for CS from (Nowak et al., 2021).

Phase 5	Improvement and future planning

The improvement and future planning phase is necessary for all the stakeholders involved since it ensures the learning process and gives an opportunity to create more engaging Citizen Science projects in the future. Following actions should be considered:

- Establish long-term contact with schools. To establish CS projects in the long term, it is recommended to define CS contact persons in universities and research institutions. Furthermore, network meetings and other meetings are a useful method to stay in touch, such as the OeAD Center, which organizes such network meetings for the contact persons in Austria. Furthermore, it is recommended to establish a contact point for CS in schools (OEAD, 2021).
- Soliciting feedback from the participants. To evaluate the experience and cooperation with researchers, students and scientists, it is recommended to conduct an open feedback session at the end of the project to improve future projects and cooperation (OEAD, 2021).
- Sustaining the project founding. Funding opportunities should also be sought for the future to be able to finance further CS projects (OEAD, 2021).

2.3 Horizontal Design Principles for Running Citizen Science Projects

Eventhough the phases defined in the previous section provide guidance on the phases each project has to go trought to be successful, some important **horizontal design principles** have to be defined. In this regard, design principles are a set of considerations that form the basis of any Citizen Science project in schools. Following six principles were identified during the literature review.

Design principle 1	Constant feedback and open-ended communication

To provide students with the opportunity to improve, the participants of Citizen Science projects should receive feedback during the whole phase of activities (European Citizen Science Association & others, 2015; Pocock et al., 2013; Tweddle et al., 2012; U.S. GSA, 2021).

Design principle 2	Diversity and inclusion

Based on the principles of Service Learning (see Section 1.2) the community should be understood not only as contributors but also as beneficiaries of Citizen Science projects. According to Hidalgo et al. (2021), Citizen Science research design process should be inclusive, flexible, and adaptive in all its stages, from research question formulation to evidence-based collective results. Another key aspect of engaging participants is to ensure the diversity of the group. There are many benefits to diverse groups that are not limited to citizen science: They tend to be more creative, more productive, and perform better in general (Page, 2014). In Citizen Science specifically, diverse teams can help to develop new approaches, see issues from different angles, and ensure that project results are useful for a wider proportion of the communities they affect (Intemann, 2009).

Design principle 3	Transparency

Citizen science projects rely on a community of participants and professionals. Trust and mutual recognition amongst actors are key to achieve the necessary level of cooperation leading to success. Complete transparency is a key factor in building and maintaining that trust between different stakeholders in Citizen Science projects.

Design principle 4	Building on the knowledge already generated

For successful development of Citizen Science projects, it is helpful to draw on existing learning materials, such as Open Educational Resources (OER). If the OER materials are distributed under a CC BY SA, CC BY or Public Domain license (creative commons, 2021), materials can be edited, shared and made publicly available. In addition, existing OER materials can be tailored to the needs of educational CS trials or projects. The advantage of this is that they are accessible free of charge. The use of existing learning scenario materials facilitates easier integration since it offers a reduction of the workload for teachers.

Design principle 5	Use of creative environments

FabLabs and other creative environments could serve as the main hub for CS projects (See section 1.3). These can / could be part of schools but also collaboratively used spaces. FabLabs have a particular potential in STEM Education, given that students who participate in these settings "implement scientific knowledge while gaining relevant technical skills and developing the art of creative thought” (Stephenson & Dow, 2014). These spaces expand the opportunity to transform educational paradigms as they promote the maker culture, challenging traditional models of teaching and learning.

Design principle 6	Research ethics

According to Thuermer et al. (2022), research should do no harm - this is true for professional science, as well as citizen science. Projects should consider what potential harm their activities could cause, to their participants, their objects of study, or their wider environment. When embarking on a project, all potential risks should be identified and assessed, and mitigation strategies developed, preferably in a formal risk assessment. Projects will have inherent risks to participants, which can constitute anything from inadvertent exposure to harmful materials while collecting samples, to exposure of sensitive personal information. Participants should be made expressly aware of the risks and mitigation strategies that may affect them prior to commencing their engagement in the project. The principle of informed consent to engagement and the risks it entails is vital; merely gaining acknowledgement does not suffice. The risks of engaging with a project must be explained in plain terms, such that the citizen scientists have understood the possible implications of their participation, and actively agreed to take these risks for themselves.

3 FabCitizen Competency Framework

In the following, we describe the FabCitizen Competency Framework which supplements the Pedagogical Framework presented in Section 2. The comprehensive framework combines competencies from the fields of Citizen Science, Data Literacy and Scientific Literacy. Based on the initial analysis, we aimed at thoroughly understanding requirements and barriers in schools. In the following, we show our study design and results.

3.1 Theoretical background: Competency Definitions

In the following, we define concepts needed for the competency framework based on our initial literature review.

Definition	Competencies

We follow Pawlowski & Holtkamp (2012) in defining "*competency as a collection of skills, abilities, and attitudes to solve a problem in a given context*". In a similar manner, Ferrari (2020) distinguishes the term "competency" into three areas: "knowledge, skills and attitudes". The following definitions are provided for these areas:

- "*Knowledge refers to the result of assimilating information through learning. In addition, knowledge is the collection of facts, principles, theories, and practices that can be related to a field of work or study can be associated with*." (Ala-Mutka, 2011, p. 19)
- "*Skills refer to the ability to apply knowledge and use know-how to complete tasks and solve problems*." (Ala-Mutka, 2011, p. 19)
- "*Attitudes can be understood as the motivators of performance. Attitudes include aspects such as ethics, values, and priorities*." (Ala-Mutka, 2011, p. 20)

Several other authors provided models for the classification of competencies. Becker and Spöttl (2015) advocate a classification of competencies on the following levels (Becker & Spöttl, 2015, p. 14): (1) routine tasks; (2) skilled structured tasks; and (3) unstructured tasks. Spöttl and Becker (2015) base their competency level model on the competency level model of Dreyfus & Dreyfus (1980). Through knowledge and increased experience, employees can improve their competency level. Dreyfus & Dreyfus (1980) provide the following level gradations for this purpose (Dreyfus & Dreyfus, 1980, pp. 2-14): (1) novice (novices); (2) advanced beginner (leaner); (3) competent actor (competent); (4) skilled professional (proficient); and (5) expert (expert).

3.2 Competency Models for Citizen Science

In this chapter, several competency types relevant to citizen science implementation will be described. The two main competencies are (1) "data science" / "data literacy" and (2) "citizen science" and "scientific literacy" competencies. Therefore, different competency frameworks with the underlying approaches (e.g. job-advert analysis approaches, curriculum and other approaches) will be presented.

3.2.1 Scientific Literacy and Citizen Science

The literature review conducted by the study team revealed that for scientific literacy (Kembara et al. 2020; Gormally et al. 2012; Queriga-Dios 2020; Holbrook & Rannikmae, 2009; Udompong, Traiwichitkhun, & Wongwanich, 2014; Norris & Philips, 2003) more competency models than for citizen science (Jenett et al. 2016; Philipps et al. 2018; Aivelo & Huovelin, 2020) can be found. This is expected given the novelty of the citizen science concept.

Aivelo & Huovelin (2020) conducted a case study on students' perceptions of learning and interest in an urban rat project in the context of the Helsinki Urban Rat Project. In the project, the students surveyed rat occurrence in near environments. Aivelo & Huovelin (2020) conducted a qualitative case study (i.e. group interviews and theory-guided content analysis) on the students' perception of citizen science participation and identified the following competencies: Provide learning opportunities for participating students (teachers); Guiding & mentoring participants (teachers); Teachers & students' needs to be aligned with research; Teachers must react to the experience and outcomes; Discussion in the classroom on objective, problems and experiences; Participation in scientific research; Analysis of data; Knowledge about research method; Data collection; Doing research oneself; Participation in a project; Planning a project; Having knowledge (Factual; Conceptual; Procedural; Metacognitive).

In the publication "*Motivations, learning and creativity in online citizen science*" (Jennett et al., 2016), participants of online citizen science projects were surveyed to determine the motives (motivations) and experiences gained (learnings). Furthermore, they created a map of volunteers' motivations and their gained experiences (Jennett et al., 2016) illustrated in Figures 1 & 2.

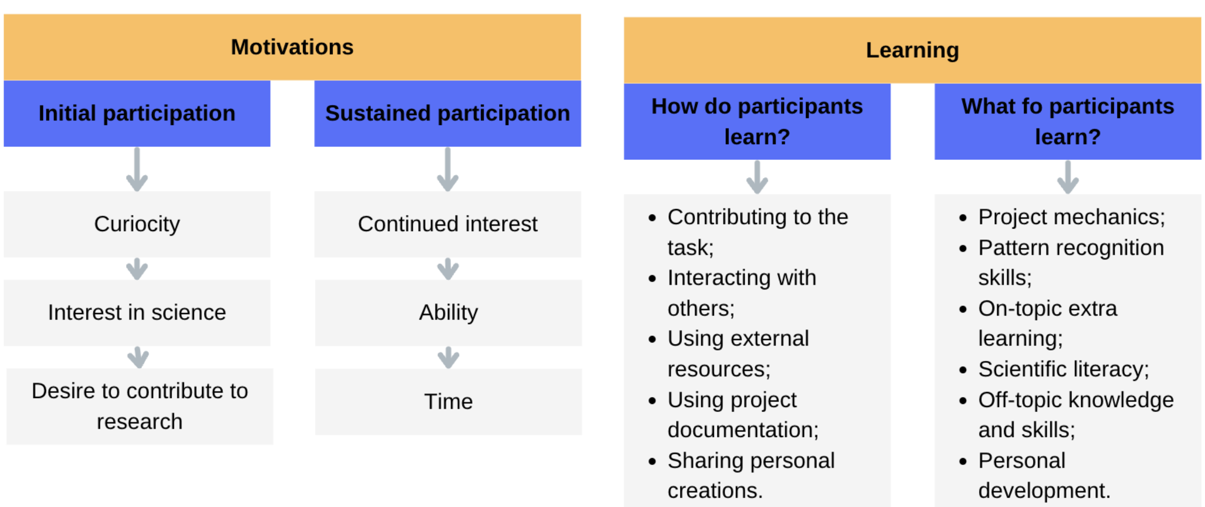


Figure 1: Map of volunteers' motivations (Jennett et al. 2016)

Figure 2: Thematic map of volunteers' learning (Jennett et al. 2016)

The purpose of the study by Gormally et al. (2012) was to develop a scientific literacy skills test. The test was developed following a seven-step process. As an important outcome, the authors defined the following categories for scientific literacy: (1) Understanding the methods of inquiry that lead to scientific knowledge (Identify a valid scientific argument > Evaluate the validity of sources > Evaluate the use and misuse of information > Understand elements of research design and how they impact scientific findings / outcomes) and (2) Organize, analyze, and interpret quantitative data and scientific information (Create graphical representations of data > Read and interpret graphical interpretations of data > Solve problems using quantitative skills, including probability and statistics > Understand and interpret basic standards > Justify interferences, predictions and conclusions based on quantitative data).

In the paper "A Framework for Articulating and Measuring Individual Learning Outcomes from Participation in Citizen Science", the authors (Phillips et. al. 2018) deal with survey methods for measuring learning outcomes within citizen science projects. Furthermore, outcomes are defined and suggestions for the learning process are made. Moreover, they define a framework for articulating and measuring individual learning outcomes from participation in citizen science (Phillips et al. 2018b).

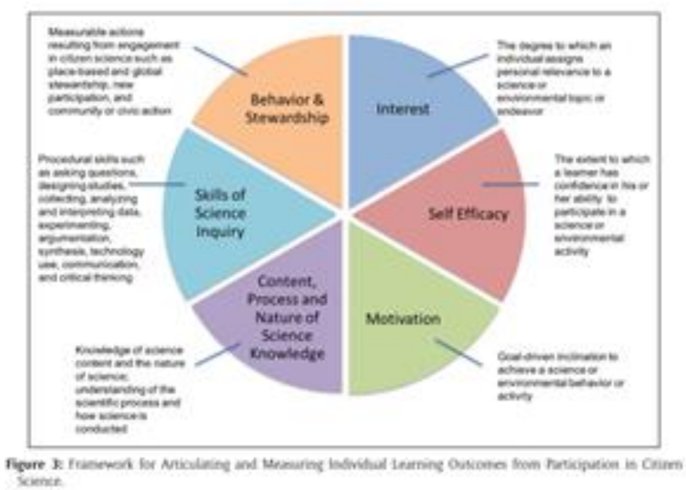


Figure 4: Framework for articulating and measuring individual learning outcomes from participation in citizen science (Phillips et al. 2018b)

In the paper "Citizen Science for Scientific Literacy and the Attainment of Sustainable Development Goals in Formal Education" a group of Spanish researchers deals with the promotion of Citizen Science in school education. The conceptual model put forward by the research group includes three dimensions (illustrated in Figure 5 below).

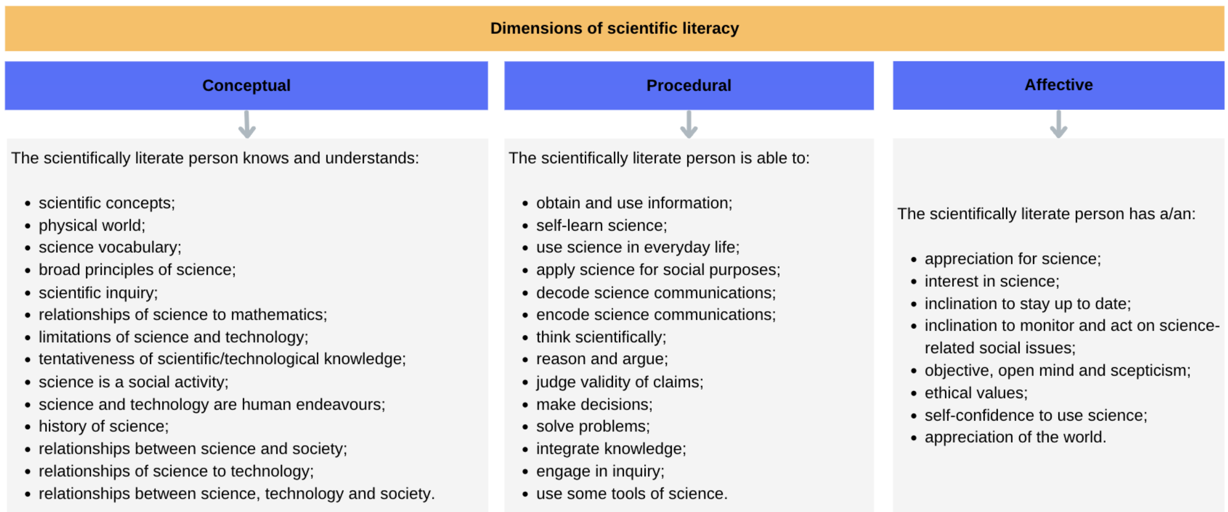


Figure 5: A composite outline view of elements of scientific literacy groups by dimensions (Kemp, 2002), cited from (Queiruga-Dios et al. 2020)

The following changes were observed among the students: (1) increase in scientific literacy; (2) increased interest; (3) curiosity and appreciation of Citizen Science in everyday life; (4) discussions and advocacy as well as presentation of the information and (5) critical reflection.

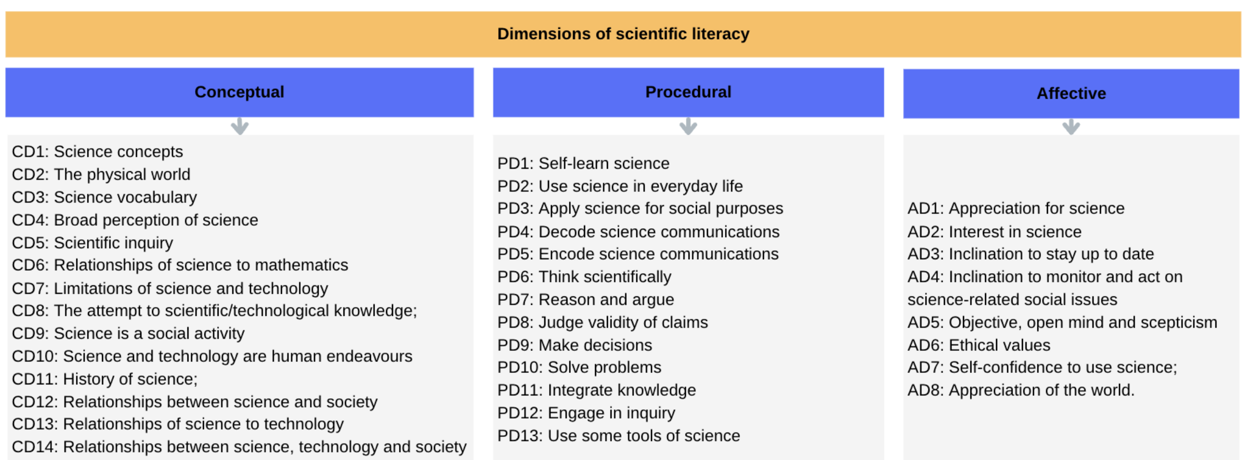


Figure 6: Overview of citizen science / scientific literacy competencies (Queiruga-Dios et al., 2020) adapted from (Kemp, 2002)

Kembara et al. (2020) did a study on the scientific literacy profile of student teachers. The research method they used was a mixed method with sequential explanatory design. Data were collected by 1) test of scientific literacy, 2) attitude scale and by 3) interviews. The authors identified three main indicators of scientific competence (Kembara et al. 2020): (1) Identifying scientific issues; (2) Explaining phenomena scientifically; and (3) Using scientific evidence. An important outcome of their study is that the ability of non-natural teacher candidates is very low in scientific literacy.

Holbrook & Rannikmae (2009) provide an overview of scientific literacy with a focus on the "scientific" and "literary" aspects. They consider the teaching of scientific literacy by comparing "education through science" and "science through education". Broad literature review was used to define the following foundational competencies: Knowledge of the substantive content of science and the ability to distinguish from non-science; Understanding science and its applications; Knowledge of what counts as science; Independence in learning science; Ability to think scientifically; Ability to use scientific knowledge in problem solving; Knowledge needed for intelligent participation in science-based issues; Understanding the nature of science, including its relationship with culture; Appreciation of and comfort with science, including its wonder and curiosity; Knowledge of the risks and benefits of science; Ability to think critically about science and to deal with scientific expertise.

Finally, Holbrook & Rannikmae (2009) provide the following definition about enhancing scientific literacy through science education: *“Developing an ability to creatively utilize appropriate evidence-based scientific knowledge and skills, particularly with relevance for everyday life and a career, in solving personally challenging yet meaningful scientific problems as well as making responsible socio-scientific decisions*.”(Holbrook und Rannikmae 2009, p. 286)

The purpose of study by Udompong et al. (2014) was to investigate the latent model of research literacy about teachers' and students' scientific literacy (Udompong et al. 2014). A qualitative method was used to validate the theoretical model and expert interviews were conducted. The researchers summarized the results of the survey in a model (see Figure 7).

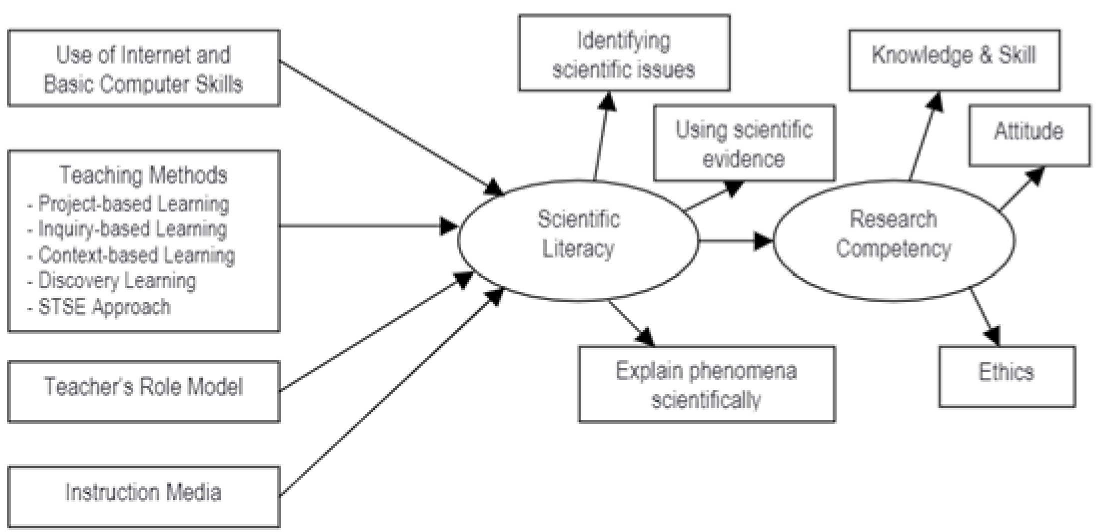


Figure 7: Causal model of research competency via scientific literacy (Udompong et al. 2014)

The paper of Norris & Phillips (2003) draws on the distinction between the basic and derived literacy to show that concepts of scientific literacy consider derived literacy but there exists a tendency to neglect the basic literacy. The authors present the view of scientific literacy competencies as scientific literacy is used in different ways:

- Knowledge of the substantive content of science and the ability to distinguish science from nonscience (CMEC, 1997; Mayer, 1997; NRC, 1996; Shortland, 1988);
- Understanding science and its applications (DeBoer, 2000; Eisenhart, Finkel & Marion, 1996; Hurd, 1998; Shen, 1975; Shortland, 1988);
- Knowledge of what counts as science (DeBoer, 2000; Hurd, 1998; Kyle, 1995a, 1995b; Lee, 1997);
- Independence in learning science (Sutman, 1996);
- Ability to think scientifically (DeBoer, 2000);
- Ability to use scientific knowledge in problem solving (AAAS, 1989, 1993; NRC, 1996);
- Knowledge needed for intelligent participation in science-based social issues (CMEC, 1997; Millar & Osborne, 1998; NRC, 1996);
- Understanding the nature of science, including its relationships with culture (DeBoer, 2000; Hanrahan, 1999; Norman, 1998);
- Appreciation of and comfort with science, including its wonder and curiosity (CMEC, 1997; Millar & Osborne, 1998; Shamos, 1995; Shen, 1975);
- Knowledge of the risks and benefits of science (Shamos, 1995);
- (k) Ability to think critically about science and to deal with scientific expertise (Korpan
- et al., 1997; Shamos, 1995).

The whole literature comparison and the competency matrix for citizen science and scientific literacy can be found in Literature competency analysis.

3.2.2 Competency Models for Data Literacy and Data Science

Starting definitions for data literacy and data science

Data science is an interdisciplinary field and requires systemic thinking, methodologies and approaches to help the development of machine learning. Following definitions could be used to describe data science and scientists.

Definitions	Data scientists / Data science
	• "*Data Scientist means a professional who uses scientific methods to liberate and create meaning from raw data*." (Donoho 2017, p. 750); • *"We can define a Data Scientist as someone who is able to extract patterns and trends from data through certain data-related tasks, regardless of its characteristics, formats and consequently challenge" (da Silveira et al. 2020, p. 25);* • **"***Data science is a new trans-disciplinary field that builds on and synthesizes a number of relevant disciplines and bodies of knowledge, including statistics, informatics, computing, communication, management, and sociology, to study data following "data science thinking*" (Cao 2017, p. 60);

	• "*Data science = statistics ∩ informatics ∩ computing ∩ communication ∩ sociology ∩ management | data ∩ domain ∩ thinking* " (Cao, 2017, p. 60).

Data literacy is considered as one "*of the most important skills in the 21st century for organizations, employees, and citizens"* (Sternkopf & Mueller 2018, p. 5045). Moreover, Ridsdale et al. (2015, p.46) state that data literacy is "*a critical aspect and foundation for the skills (e.g. computational thinking) required in order to be successful in 21st century business, academic, social, and political contexts"*. Following definitions could be used in describing the data literacy.

Definitions	Data literacy
	• *"Data literacy is the ability to collect, manage, evaluate, and apply data, in a critical manner"* (Ridsdale et al. 2015, p. 8); • "*Data literacy is the ability to use data productively and to think about it in a critically reflective way."* (Sternkopf & Mueller 2018, p. 5045); • "*Data literacy is the ability to ask and answer real-world questions from large and small data sets through an inquiry process, with consideration of ethical use of data. It is based on core practical and creative skills, with the ability to extend knowledge of specialist data handling skills according to goals. These include the abilities to select, clean, analyze, visualize, critique and interpret data, as well as to communicate stories from data and to use data as part of a design process"* (Wolff et al. 2016).

3.2.3 Competency models for data literacy and data science

Competency models for data literacy

The literature review revealed a variety of competency models deconstructing the concept of data literacy (Grillenberger & Romeike, 2018; Ridsdale et al., 2015; Wolff et al. 2016; Bolhuis, 2017; Pothier & Condon, 2017; Prado & Marzal, 2013; Sternkopf & Müller, 2018; Mandinanch & Gummer, 2016; Kippers et al., 2018). The following chapter reviews the current research and main outcomes.

Grillenberger & Romeike (2018) developed a theoretically founded competency model for data literacy divided into two areas i.e. content and process (see Figure 8). The *content areas* reflect the Citizen Science content addressed by the competencies. The *process areas* focus on the practical activities. Both areas are intertwined since the process areas display how humans can get into touch with data, whereas the content area considers the theoretical background and the underlying concepts.

Figure 9: The developed data literacy competency model (Grillenberger & Romeike, 2018)

Ridsdale et al. (2015) also focus on data literacy and define a competence matrix (see Figure 10) with the following five competence areas: (1) conceptual framework; (2) data collection; (3) data management; (4) data evaluation and (5) data application.

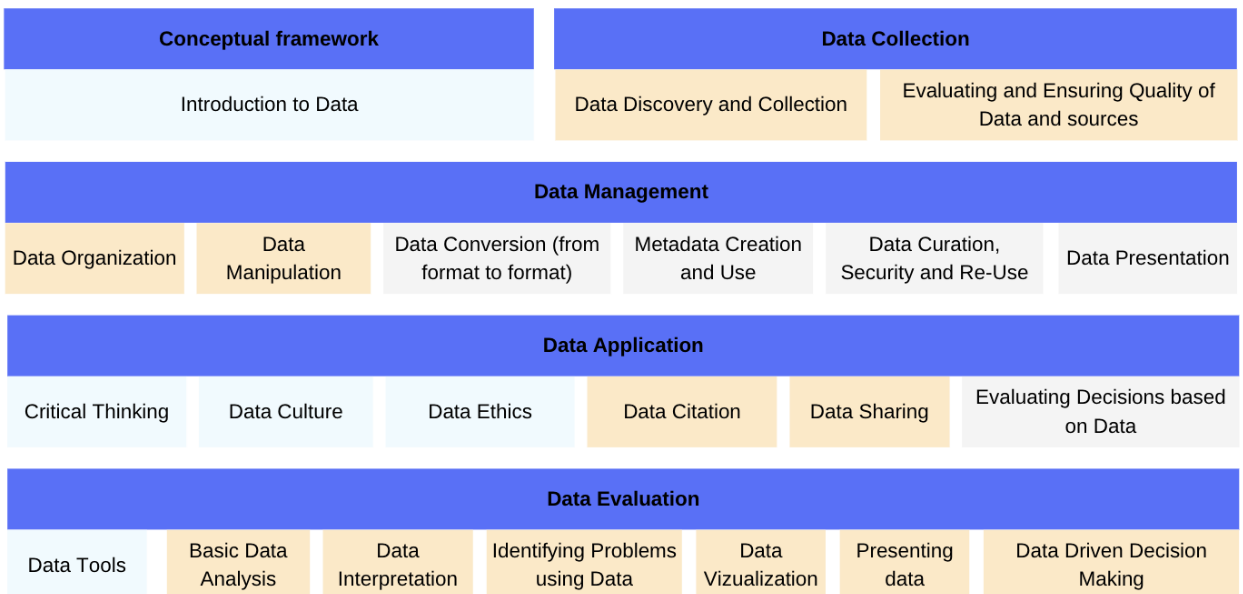


Figure 10: Data Literacy Competencies (Ridsdale et al. 2015)

Sternkopf & Mueller (2018) develop a data literacy maturity model (DLMM) for the application in the context of non-governmental organizations. The DLMM describes ten data literacy competencies divided into two broad groups - organizational and individual (see Table 1 below). The model should help to improve the understanding which skills are needed in the context of data projects (Sternkopf & Mueller, 2018, p. 5045). Sternkopf & Mueller (2018, p. 5051) also define the competency levels for data literacy including uncertainty, enlighmenet, certainty and data fluency.

Table 1: Elements of data literacy maturity model by Sternkopf & Mueller (2018)

Levels	**Competence**	**Description**

Organizational	Data culture	Promoting comfort around data (and bringing down the psychological barriers that exist between people and data).
	Data ethics and security	Processes that are in place to ensure confidentiality, integrity and availability of data is adequately protected.
Individual	Ask questions / define	Ability to ask questions to data and ultimately find the answers.
	Find	Track down sources of existing data, know how to collect data if it does not exist yet.
	Get	Describes gaining access to data or generating fresh data as well as conversion of different input formats.
	Verify	Apply critical thinking skills to data. Ability to do data quality assessment, contextualizing specific information to other aspects.
	Clean	Removing invalid record and translating columns to use a sane set of values.
	Analyze	Ability to work with statistics and other analytical methods.
	Visualize	Ability to represent findings in appropriate visual outputs.
	Communicate	Importance of finding stories and communicating them to the targeted audience.

Prado & Marzal (2013) conducted a literature review on the support and promotion of data literacy competencies in libraries. In addition, the authors compared different information literacy standards (i.e. AASL/CCS, ILSHE, ILSSET, ILSAS, PSRCG, ILCSJ). Combination of the both methods revealed a set of data literacy categories i.e. (1) Understanding data; (2) Finding and/or obtaining data; (3) Reading, interpreting and evaluating data; and (4) Managing data.

Pothier & Condon (2019) provide a “baseline set for data literacy competencies” for business students. The authors focused on the definition of a competency set of seven foundational data literacy competencies which are specifically important for business students. For this purpose, a combination of professional literature, news stories, reports, and academic literature is appropriately investigated in this study. As a result, seven foundational data literacy competencies were formulated: (1) Data organization and storage; (2) Understanding data used in business contexts; (3) Evaluating the quality of data sources; (4) Interpreting data; (5) Data-driven decision making; (6) Communicating and presenting effectively with data; and (6) Data ethics and security.

The motivation of the paper of Wolff et al. (2016) is that current definitions of data literacy are not fit for purpose since they do not consider the changing nature of the datasets and different roles and stages of applying data literacy skills. Hence, the authors aimed to examine the research literature relating to data literacy in order to identify commonalities between definitions and to disambiguate it from the more coherently defined statistical literacy (Wolff et al. 2016). By mapping the user needs and the space of individual competences that compromise the definitions of data literacy, the authors develop a framework supporting the multiple perspectives of data literacy and forming a common foundation for the teaching and learning of data literacy skills (see Figure 14). Furthermore, the authors define four types of data-literate citizens: (1) Communicators (understand the sense of data and can talk about it), (2) Readers (interpret data), (3) Makers (Can integrate data in an overall strategy and are able to identify and solve real world problems, and (4) Scientists (need skills in communication and domain-specific knowledge with regard to data). The varied roles showcase the rising complexity with regard to the roles.

Henderson & Corry (2020) did a literature review of 28 literacy articles. As a output of the paper, they created the followings recommendations for improving data literacy for professional educators:

- Create more skills-based educator preparatory programs at colleges and universities;
- Encourage collaboration among educators;
- Model and encourage data use from both quantitative and qualitative sources;
- investigate the role of technology and big data on data literacy.

Wayman et al. (2012) examine how data is used to improve classroom practice. Therefore, barriers which have negative effects regarding the attitude towards data were identified. Thereby the focus was put on the following questions:

- How do educators commonly use data?
- What is an educator's attitude towards data?
- How do principles lead faculty in using data?
- How well do computer data systems support educators in using data?

As a result, educators are ambivalent towards their use of data (Wayman et al. 2012, p. 21) as they were able to observe how data use can improve practice but the teachers were not satisfied because of the barriers that mad data use hard for the teachers "(Wayman et al. 2012, p. 21). The proposition of Wayman et al. (2012) is to support classroom practice with district policies for data use.

Mandinach & Gummer (2016) report on the development of a conceptual framework for data literacy as data use is an important issue in education. The authors define a frame for teachers which knowledge, skills and dispositions, teachers need to use "data effectively and responsible". The method consists of two important steps: (1) Analysis of published materials dealing with data literacy and (2) Interviews with 55 experts. The interviews provided insights on how the experts understand the construct of data literacy. From the interview content analysis, the definitions of the experts and the analysis of the transcripts, 100 sentences of knowledge and skills were extracted. By a further analysis of the transcripts and the definitions of experts the following categories were created: Investigation process, Thinking habits, Data Quality, Data properties, Procedural skills for data use, Transformation of data into information and Transformation of information into implementation. After a selection process, the remaining 59 competencies from both studies were categorized in six categories / components (see Table 2).

Table 2: Conceptual framework for Data Literacy for Teachers (DLFT) by Mandinach & Gummer (2016)

Domain	Description	Examples of related skills and knowledge areas
Identify problems and frame questions	Identify issues with topical areas, curriculum, instruction or student(s)	Articulate problem of practice Understand the context Involve stakeholders
Data use	Understand difference sources of data; how to identify generate and use these	Identify possible sources of data Understand what data are appropriate Understand specificity of data to question/problem Understand how to analyze data Manage data
Transforming data into information	Moving data towards information which can inform teaching	Understand how to interpret data Assess patterns and trends Problem for causality Summarize and explain data
Transforming information into decisions	Using the inquiry cycle to inform instruction	Determine next instructional steps Monitor student performance Diagnoze student needs Make instructional adjustments
Evaluation of outcomes	Evaluate the outcomes of changes to practical use data as part of an iterative cycle of inquiry.	Compare performance pre- and post-decisions Monitor changes in classroom practices Monitor changes in students' performance Consider iterative decision cycles

Mandinach & Gummer (2013) deal with the need for data-driven decision-making in the programs at schools. The following aspects are identified by the researchers in the context of data literacy as important (Mandinach und Gummer 2013, pp. 31-32):

- Differentiate instruction to meet the needs of all students.
- Formulate hypotheses about students' learning needs and institutional strategies.
- Collect and use multiple sources of data.
- Use formative, summative, interim, benchmark, and common assessments, as well as student classroom work products, to make decisions.
- Modify instructional practice according to the data collected (Abbott, 2008; Bernhardt, 2008; Mandinach et al., 2008)
- Drill down to the item level to gain a deeper understanding of performance (Boudett et al., 2007; Love et al., 2008)
- Use student work, not just tests, and other sources of data (Bernhardt, 2008; Boudett et al., 2007; Halverson et al., 2007; Supovitz & Klein, 2003; Wayman & Stringfield, 2006)

- Monitor outcomes (Easton, 2009; Love et al., 2008; Mandinach et al., 2008)
- Focus on all children, not just the “bubble kids” (BooherJennings, 2005; Brunner et al., 2005; Love et al., 2008)
- Look for causes of failure that can be remediated (Boudett et al., 2007; Love et al., 2008)
- Work in data teams to examine data (Halverson et al., 2007; Long et al., 2008)

By taking a system-based approach, Mandinach & Gummer (2013, p.34), substantiate that with “*systemic thinking the relations and interrelationships between components of a complex system can be understood*”. The authors observe the actors and the stakeholders which are participating in this system: Schools of education, School districts and PR actioners, Professional development provider, State education agencies and Professional organizations. Furthermore, Mandinach und Gummer (2013) state that data-driven decision-making must become part of an educator’s preparation program and the schools are the center where important educational experiences must be gained. The authors also identify following research gaps i.e. how educators can acquire data literacy, need for research on the impact of data and research on development needs for educators (different needs among the educators).

Competency models for Data Science

Hattingh et al. (2019) conducted a literature review of data science competencies scanning 139 titles and created a unified data science competency model. The findings were grouped into the following competency themes: organizational, technical analytical, ethical and regulatory, cognitive and social (see Table 7).

Table 7: Unified data science competency model (Hattingh et al., 2019)

Domains of competencies	Description
Organizational	Contextual knowledge; Domain knowledge; Management skills; Strategic thinking.
Analytical	Understanding the business context; Supporting the technical competence.
Technical	Big data management; Computational intelligence; Computer Architecture; Computer networking; Computer programming; Computer security; Data visualization, Statistics; Software development; Mathematical modeling.
Ethical and regulatory	Information ethical issues; Social responsibility; Regulatory and policy issues.
Cognitive	Critical thinking; Problem solving; Solutioneering; Visual intelligence; Self-management.
Social	Communication; Collaboration; People aspects.

Donoho (2017) did a review of the current data science movement and distinguished between “*lesser data science*” and the larger field “*greater data science*” (GDS). The larger field of data science focuses on every step that the professional must take from getting acquainted with the data all the way to delivering results based upon it. Moreover, the author concerned with the development of data science from statistics and the article provides an overview about the most important aspects of scientific data research. Donoho (2017) sees data science as a new area including statistics but from a more wide perspective. On the base of GDS, the author formulated the following six dimensions: (1) Data Exploration and Preparation; (2) Data Representation and Transformation; (3) Computing with Data; (4) Data Modeling; (5) Data Visualization and Presentation and (6) Science about Data Science.

Shirani (2016) applied a job-adverts analysis approach by using “RapidMiner” as a text mining software “Kdniggets.com” and “r-bloggers.com” were used as job sources. Based on the data analysis, the authors formulated a taxonomy of data science and analytic competencies consisting of the columns “data science and analytics”, “big and relational data analytics”, and the rows “advanced skills”, “introductory to intermediate skills”, “foundational competencies” and “soft skill” (see Table 3). To summarize, the aim was to identify data science competencies based on the industry demand. An interesting outcome is that employers placed as much emphasis on soft skills as on hard skills.

Table 3: Taxonomy of Data Science and Data Analytics competencies by Shirani (2016)

(Traditional) data science and analytics	“Big” and relational data analytics	
	Big data analytics	Relational data management and analytics
Advanced skills		
Data product development (with R Shiny package) Deep learning: recurrent neural networks, reinforcement learning, natural language processing Ensemble learning, random forests, unidirected graphical models.	Enabling frameworks and languages: Apache Hadoop, Spark, Hive, Yarn, Tensor Flow Java, Scala or Python Spark SQL, Hive SQL Streaming data analytics Temporal and geospatial data analytics Network analytics Text and latent semantic analysis	Data warehousing: dimensional modeling, extraction, transformation and loading (ETL); dimensional data visualization - dashboards and scorecards; Advanced SQL.
Introductory to intermediate skills		
Required: Math and statistics background	Required: Database and programming background	
Classification and regression: neural networks; classification and regression trees; support vector machines; genetic algorithms; linear regression; non-linear regression; logistic regression; Bayesian classification. Association: linke and sequence analysis (apriori algorithm; graph-based techniques) Cluster abalysis: k-means, hierarchical	Hadoop, MapReduce, HDFS concepts NoSQL databases: HBase, Cassandra, MongoDB Hive & Hive SQL Spark programming Scala, Java and/or Python programming	Procedural extensions to SQL Intermediate SQL The relational data model; normalization; ER diagrams

Text mining, web analytics		
Foundational competencies		
Hard skills Math and statistics background (linear algebra, calculus, probability, statistics) R programming	**Hard skills** Intro to programming: Java, Python, Scala or C++/C# Intro to structured Query Language (SQL)	
Soft skills Communication; Teamwork; Problem-solving; Critical thinking		

Da Silveira et al. (2020) also analyzed the competency requirements for data scientists. Soft skills and technical skills should be analyzed through a qualitative and a quantitative typology. The authors formulated an important key message that according to their research "most companies do not care about the degree and education level of the candidate, but about the necessary soft skills and technical competences". Furthermore, they identified a trend towards a multidisciplinary profile. The following competencies were identified as the most important: Communication, Team Player, Problem Solver, Python, English and SQL.

The data (i.e. job descriptions of data scientists) was extracted from the LinkedIn social network. The search Location was limited to Brazil. The search terms used include "Data Scientist" and "Data Scientist" in Portuguese language. The results of the study revealed following names used for the profession of a "data scientist": big data analyst, big data architect, big data consultant, big data engineer, big data specialist, computer scientist, data analyst, data engineer, data strategist, data science analyst, data science consultant, decision strategist, machine learning engineer. The main requirements for hard skills are outlined in Figure 20. Furthermore, it was possible to draw a line between the six dimensions of the Data Scientist according to Donoho (2017) and the job-adverts-analysis conducted in this paper (see Table 4).

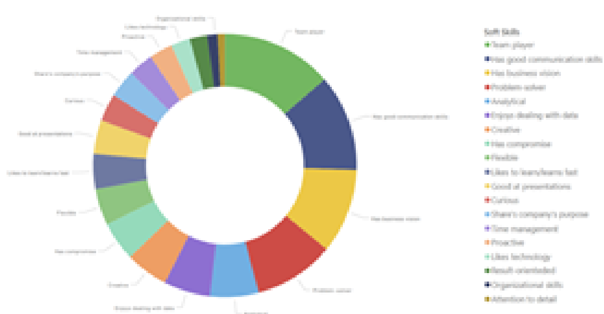


Table 4: Relationship between the six dimensions and the skill classes by Da Silveira et al. (2020)

Dimension	Hard skills	Soft skills
Basic skills in all dimensions	Common skills (coding skills, Excel, English) Operational system (Linux) Distributed version control system (GIT)	Flexible, Time management, Proactive, Good at presentations,

		Can compromise, Team player
1. Data exploration and preparation	Data manipulation (Database NoSWL, Big data tools, ETL tools, SQL, Hive)	Attention to detail Organizational skills, Curiocity, Shares company's purpose
	Data modeling and analysis (Data modeling, Data analysis, Mathematical knowledge, Statistical knowledge)	Enjoys dealing with data, Analytical, Has business vision, Has good communication skills
2. Data representation and transformation	Programming language (Pandas (library), Java, Scala, R, Python) Artificial intelligence techniques (Data mining, Machine learning) Distributed database systems (Oracle, Hbase) Data manipulation (Database No SQL, Big Data tools, ETL tools)	Result oriented, creative, enjoys dealing with data, has business vision
3. Computing with data	Frameworks for clustering and large-scale data analysis (MapReduce, Spark) Platforms for distributed systems (AWS, Kafka, Hadoop) Distributed database systems (Oracle, Hbase) Programming language (Pandas (library), Java, Scala, R, Python)	Likes technology Likes to learn/learns fast Enjoys dealing with data Problem-solves
4. Data visualization and presentation	Programming language (Pandas (library), Java, Scala, R, Python) Data manipulation (Database No SQL, Big Data tools, ETL tools) Data modeling and analysis (data modeling, data analysis, mathematical and statistical knowledge)	Proactive, shares company's purpose, creative, analytical, has business vision, has good communication skills
5. Data modeling	Artificial intelligence techniques (Data mining, Machine learning) Data modeling and analysis (data modeling, data analysis, mathematical and statistical knowledge)	Shares company's purpose Likes to learn/learns fast Creative Analytical Problem-solver
	Frameworks for clustering and large-scale data analysis (MapReduce, Spark)	Likes technology Proactive
6. Science about data science	Artificial intelligence techniques (Data mining, Machine learning) Data modeling and analysis (data modeling, data analysis, mathematical and statistical knowledge)	Curios Shares company's purpose Likes to learn/learns fast Analytical Problem-solver Has business vision

Furthermore, Saltz et al. (2018) define the following three types of data science programs: (1) Data analytics, (2) Applied Data Science and (3) Foundational Data Science. The program "data analytics'' has the advantage that it applies data science concepts in a business context (Saltz et al. 2018, p. 618). For example, the program enables the students to use and apply Data Science as for example to use tools as Tableau, SAS and IBM SPSS (Saltz et al. 2018, p. 618). Therefore, the program “data analytics” “*needs to teach visualization and communication skills more than the other types of data science programs”* (Saltz et al. 2018, p. 618). The program “applied data science” puts the focus more on technical aspects e.g. programming languages, R and python (Saltz et al. 2018, p. 618). Therefore, the students are able to generate deep data insights. Often these programs also focus on data engineering so that it is possible that students get data from API’S and optimize the data storage.

Konsky et al., (2016) investigated the role of SFIA (Skills For the Information Age) in ICT (Information and Communication Technologies) curriculum design and provided recommendations on the use of SFIA for curriculum design and management. The authors map the Data Scientist career role descriptions to the SFIA (see Table 6 below).

Table 6: Data scientist role descriptions mapped to SFIA by Konsky et al. (2016)

Principal SFIA skills	Relationship to the data scientists’ career role
Analytics (INAN)	Data scientists analyze data to discover and quantity patterns in information using statistics, statistical inference, regression analysis and machine learning.
Data Analysis (DTAN)	Data scientists manage data requirements and establish, modify data structures leading to the retrieval, transformation and analysis of data.
Methods and tools (METL)	Data scientists ensure appropriate methods and tools are applied to retrieve, transform, curate, visuaize and analyze data and to build related data products.
Consultancy (CNSL)	Data scientists consult with clients to recommend and implement approaches to address client business questions, leading to new insights and knowledge, informing decision making and predicting outcomes.
Research (RSCH)	Data scientists form and test hypotheses based on a statistically rigorous and repeatable methodology involving the analysis of complex data sets.
Technical Specialism (TECH)	Data scientists require specialist knowledge in a range of topics including statistics, statistical inference, high performance computing and visualization.
Project management (PRMG)	Data scientists manage data science projects within agreed parameters of cost, time scale and quality.
Programming / Software development (PROG)	Data scientists write programs and integrate custom-off-the-shelf solutions to retrieve, clean, transform and visualize data and build predictive data products that inform business decisions.

Following Konsky et al., (2016, p.11) define recommendations of the use of SFIA for the curriculum development: (1) Consult established resources that specify ICT position descriptions in terms of SFIA descriptors and levels. In those cases, where an appropriate set of position descriptions is not available, skills for the intended ICT role should still be mapped to SFIA; (2) Use SFIA as part of a holistic approach to ICT curriculum design and management (3) Conduct professional development training for academic staff to ensure an adequate understanding of SFIA and its relationship to professional practice in ICT; and (5) Use SFIA descriptors to inform the design of authentic learning activities and assessments, while taking into consideration the relationship of these to Bloom's Cognitive Levels.

Sentance (2017) discusses data science from the perspective of the computing curriculum in schools. The author perceived data literacy as an important forerunner to data science and incorporates key skills in identifying, collecting, and analyzing data. Three important building blocks for building data science curriculums were identified in the study: (1) Data Collection and analysis (identification and collection of data; understanding data is part of the computational thinking); (2) algorithms and programming (using a programming language, development of algorithms); and (3) ethics and moral issues (impact of automation on society; impact of collecting large amounts of data about people's privacy). In addition to literature analysis, a small-scale-survey with teachers (n=36) to get the opinion about data science in the computing curriculums in the UK. Two important statements were that one should avoid overloading the curriculum and that Implications of big data, machine learning and artificial intelligence are important topics which should be incorporated in the computing curriculum.

In addition, Sentance (2017) mentioned an example project "the Urban Data School" where Smart City datasets are analyzed to use data literacy skills. In the Urban Data School Project Smart City datasets are analyzed to use data literacy skills. The following skills are discovered: (1) Use of datasets; (2) Developing data skills and (3) Enabling people to tell data stories. The identified challenges by Sentance (2017) are that computing does not already exist as a subject in school, to have a balanced data science curriculum that teachers need to be confident in the subject and also the lack of gender balance in data science courses. Furthermore, Sentance (2017) sums up computer-related computational thinking skills which can be incorporated into different lessons (see Table 7).

Table 6: Data-related computational thinking skills (adapted from Barr & Stevenson 2011) cited from (Sentance, 2017)

Computational thinking skills	Computer science	Mathematics	Science	Social studies
Data collection	Find a data source for a problem are	Find a data source for a problem are, for example, flipping coins or throwing dice	Collect data from an experiment	Study battle statistics or population data
Data analysis	Write a program to do basic statistical calculations a set of data	Count occurrences of flips, dice throws and analyzing results	Analyze data from an experiment	Identify trends in data from statistics

Summarizing the section on competencies, we conclude that the identified citizen science skills in the user guide for citizen science by Phillips et al. (2014) and additionally identified CS, Data Science, Scientific Literacy and data literacy skills will be used to create a competency framework for CS in IS for the educational context.

Regarding the literature, the problem occurs that many CS projects do not include Scientific and Data Literacy competencies or neglect the previous research on related areas like data and scientific Literacy (Qaurooni et al. 2016). Considering the complexity of Data Science competencies, Data Literacy is more appropriate than Data Science for the target group of secondary level 1, since students in secondary level 1 need to learn the basic skills with data first. Data Science is a more appropriate approach for higher grades, which however are not the target group of the current competency framework. Since data literacy can be viewed as a forerunner of Data Science, the concept of data literacy is considered for the development of a competency framework for CS which includes data related competencies. By further investigating the concepts and definitions of data literacy and data science, it becomes clear that for the classes from 5-9 rather data literacy and less data competencies are needed since Data Science is more complex (Hattingh et al. 2019) and data literacy competencies fit better the purpose for the classes 5-9 (Henderson and Corry 2020; Sapp Nelson 2020). This is the reason why a combined map of Scientific Literacy, CS and data literacy competencies is created.

3.3 Competency Descriptions

There are a variety of competency description schemes in order to ensure a common vocabulary and structure of competencies.

As a first approach, common vocabularies have been developed, often on the basis of the learning outcome taxonomies of the cognitive domain (Bloom et al, 1956) and affective domain (Krathwohl et al, 1964). An example for such a taxonomy are the levels and corresponding verbs by Paquette (2014).

Table 8: Skill Taxonomy by Paquette (2014)

1	2	3
Receive	1. Pay Attention	
	2. Integrate	2.1 Identify 2.2. Memorize
Reproduce	3. Instantiate / Specify	3.1 Illustrate 3.2 Discriminate 3.3. Explicitate
	4. Transpose / Translate	
	5. Apply	5.1 Use 5.2 Simulate

Create	6. Analyze	6.1 Deduce 6.2 Classify 6.3 Predict 6.4 Diagnoze
	7. Repair	
	8. Synthesize	8.1 Induce 8.2 Plan 8.3 Model/construct
Re-invest	9. Evaluate	
	10. Self-manage	10.1 Influence 10.2 Self-control

The revision of the learning goal taxonomies of Bloom (1956) (Anderson & Krathwohl, 2001) names six levels. These differ in the degree of complexity and it allows a graduation of competencies according to difficulty. Learning objectives are defined on the basis of Bloom (1956) learning objective taxonomy. The following sequential learning levels are named (Anderson & Krathwohl, 2001): knowledge; understanding; application; analysis; synthesis and evaluation or assessment. Other approaches focus use ontologies such as the SARO ontology for relating job postings and structured skills (cf. Sibarani et al, 2017).

For our project, the main purpose is to describe competencies in an interoperable way and to link competencies to different curricula. Hence, the competency description aims at describing in depth competencies and their links to school curricula.

- **Competency description** describes the competency. A competency can consist of multiple skills, abilities and attitudes.
- **Competency statement** provides an operational statement which can be assessed.
- **Competency classification** describes the main subject of a competency (e.g. Scientific literacy, data literacy, …)
- **Proficiency level** describes levels of mastering competencies. In our context the levels are differentiated by roles
- **Role / level** describes either a role or a level / grade in school
- **Curriculum mapping** links a competency to one or multiple curricula.

This simple scheme fulfills the main purpose of our project - specifying a competency framework including links to national / state / school curricula.

3.4 Intermediate Summary

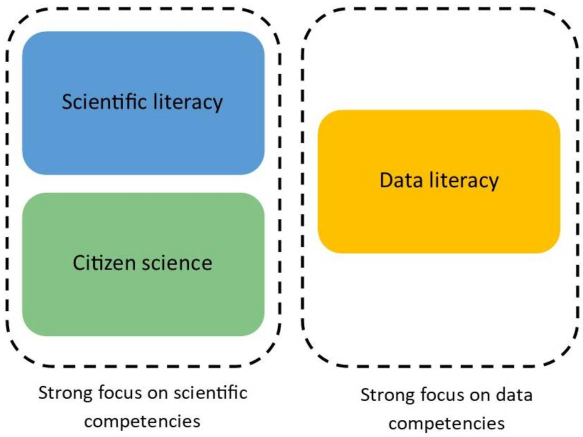
As a first step, the CS concept has been identified as important. In addition, scientific literacy (SL) has been identified as a related concept and is therefore integrated in the literature analysis. Moreover, one important goal of CS projects is to enhance the citizens' SL levels (Levy & Germonprez, 2017). Therefore, one focus is also put on data-related competencies, because data quality is considered a significant problem in CS projects (Balázs et al., 2021; Lukyanenko et al., 2016), which should be improved using a fitting competency framework that includes data-related competencies for CS. The competency framework for educational CS should fit to competencies for undertaking CS projects in secondary school I, where data literacy is considered since it is perceived as "an important forerunner to data science and incorporates key skills in identifying, collecting, and analyzing data" (Sentance, 2017, p. 81). Because data science competencies are too complicated for secondary school I, this concept is not considered, and instead data literacy (DL) is integrated into the competency framework.

The following competency areas were identified in the first analysis:

- **Scientific literacy** (Gormally, Brickman, & Lutz, 2012; Holbrook & Rannikmae, 2009; Kembara et al., 2020; Norris & Phillips, 2003; Udompong, Traiwichitkhun, & Wongwanich, 2014);
- **Citizen science** (Aivelo & Huovelin, 2020; Bonney, Ballard et al., 2009; Jennett et al., 2016; Phillips, Porticella, Constas, & Bonney, 2018; Queiruga-Dios, López-Iñesta, & Diez-Ojeda, Marío, José Benito, 2020);
- **Data literacy** (Bolhuis, Voogt, & Schildkamp, 2019; Grillenberger & Romeike, 2018; Prado & Marzal, 2013; Ridsdale et al., 2015; Sternkopf & Mueller, 2018; Wolff, Gooch, Montaner, Rashid, & Kortuem, 2016);
- **Data science** (Donoho, 2017; Murawski & Bick, 2017; Sentance, 2017; Shirani, 2016).

As a first step, the CS concept has been identified as important. In addition, scientific literacy (SL) has been identified as a related concept and is therefore integrated in the literature analysis. Moreover, one important goal of CS projects is to enhance the citizens' SL levels (Levy & Germonprez, 2017). Furthermore, one focus is put on data-related competencies because data quality is considered a significant problem in CS projects (Balázs et al., 2021; Lukyanenko et al., 2016), which should be improved using a fitting competency framework that includes data-related competencies for CS. In addition, data literacy is considered since it is perceived as "*an important forerunner to data science and incorporates key skills in identifying, collecting, and analyzing data"* (Sentance, 2017, p. 81). Because DS competencies are too complicated for secondary school I, this concept is not considered, and instead data literacy (DL) is integrated into the competency framework. Therefore, the following competency areas result (Figure 28).

Figure 28: Needed competency areas for undertaking educational CS projects in the IS context



4 Development of the FabCitizen Competency Framework

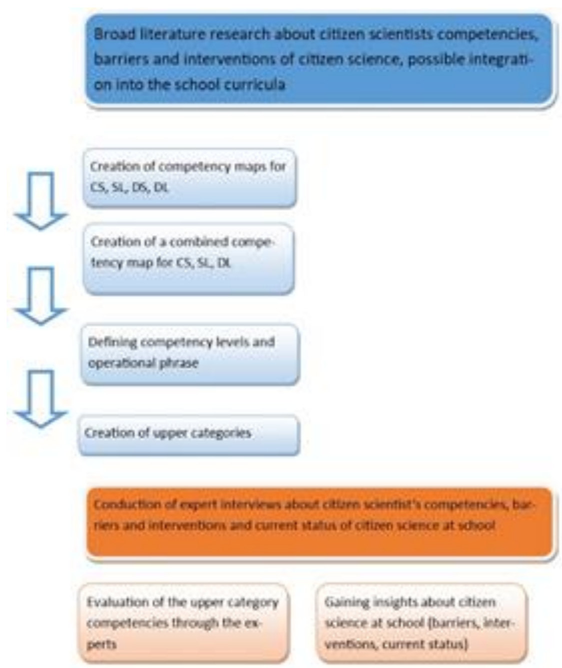
4.1 Methodology

For our analysis, we have chosen a qualitative approach. As shown in the background section, there are no extensive analyses of how Citizen Science can be brought into schools. Furthermore, there are many differences (curricula, technical equipment, competencies, …) in the participating countries. For this explorative research task, the study team decided to do semi-structured interviews as well as focus groups. The interviews were - when authorized - recorded and transcribed. The full interview guidelines are shown in Annex 1.

Overall, we apply a Design Science Research approach (Peffers et al., 2007) - this approach aims at the rigorous creation of artifacts, in our case the competency framework. As part of the problem identification, we conducted a systematic literature review including the comparison of key approaches in a concept matrix (Webster & Watson, 2002). For the evaluation of our artifact, we used a mixed method evaluation (Veneble et al, 2012).

In the following the steps of the procedure for the comparison of the models are provided.

1. Literature research of citizen science, data science, scientific literacy and data literacy competencies;
2. Definition of the anaölysis structure (name, year, author, method, evaluation method, mentioned competences);
3. Including all competencies from the analyzed approaches (citizen science, scientific literacy and data literacy competencies);
4. Formation of main categories of the competences;
6. Removal of redundancies in the main categories;
7. Division of the upper categories into knowledge, skills, and attitudes;



8. Identification of interfaces or overlaps of upper categories of citizen science, scientific literacy and data literacy;

9. Creation of the overlaps of upper categories including an activity description “I am aware of …. I do”;

10. Visualization of the overlaps of Scientific Literacy, Data Literacy and Citizen Science.

In the first step, a literature research on necessary competencies of Citizen Science projects was conducted. As a result, the competency fields “data science”, “data literacy”, “scientific literacy” and “citizen science” competencies were identified. More on, the overlapping and similarities of data literacy, scientific literacy and citizen science competencies were identified, and the competencies were collapsed into one map. Due to the smaller significance of data science, data science competencies were not considered in the combined “big map”. In a next step, upper categories were formulated to be able to evaluate the competencies in a next step through expert interviews. The upper categories were created due to the fact that it is not possible to list 200 competencies.

The competencies are evaluated through expert interviews. Furthermore, through the interview’s insights are gained about other topics as barriers and interventions for integrating citizen science at schools and the needs of students and teachers.

4.2 Competency description format

As a first step, we developed a description format for the competencies. The main aim is to describe competencies which are needed for undertaking CS projects and to link them to different curricula. Therefore, the following competency structure is proposed for describing CS-DL-SL competencies and to link them to the curricula:

- **Competency description** describes the competency. A competency can consist of multiple skills, abilities and attitudes.
- **Competency statement** provides an operational statement which can be assessed.
- **Competency classification** describes the main subject of a competency (e.g. Scientific literacy, data literacy, …)
- **Proficiency level** describes levels of mastering competencies. In our context the levels are differentiated by roles
- **Role / level** describes either a role or a level / grade in school
- **Curriculum mapping** links a competency to one or multiple curricula.

Using this scheme helps to specify a competency framework including the links to national / state or school curricula.

The following categories are integrated in the competency map.

- Category of the competency
- Description of the competency
- Operational description of the competency
- Competency level descriptions for
    - Secondary school I, Grade 5-6

    - Secondary school II, Grade 7-10
    - Teachers
- Reference of the competence formulation (curricula or own formulation)
- Learning material example (OER-learning materials)

The whole competency map can be retrieved under:
https://docs.google.com/spreadsheets/d/110iI0IaBUw5b3UG4_6Iomg6jQnelWQYWa-KG4dWbrgU/edit?usp=sharing

4.3 FabCitizen Competency Categories

In this part, we show the preparations for the development and implementation of the competency framework.

4.3.1 Initial Evaluation: Results and Implications

As a starting point, the competency framework was divided into categories to provide a clear and intuitive structure. This structure has been validated in different formats.

Since there are many categories in the first version of the CS-DL-SL competency set, an expert-driven approach was used as a focus group to make the competency set more precise and adequate through a participatory approach, where the author had a moderating role and the actors engaged in a dual role of co-researchers and co-subjects (Breu & Peppard, 2001).

Table 10: Participants of the further development of the competency set (own created)

Function	**Knowledge area**
Professor	Business computer science
Researcher	Industrial design, product design and development
Researcher	Technical expert at fabrication laboratory
Professor	Social technologies, communication, and information management
Researcher	Information systems, competency models

The detailed results of competency allocation can be found in Appendix B: Allocated competencies in the workshop. The following upper-level categories emerged from the competency workshop.

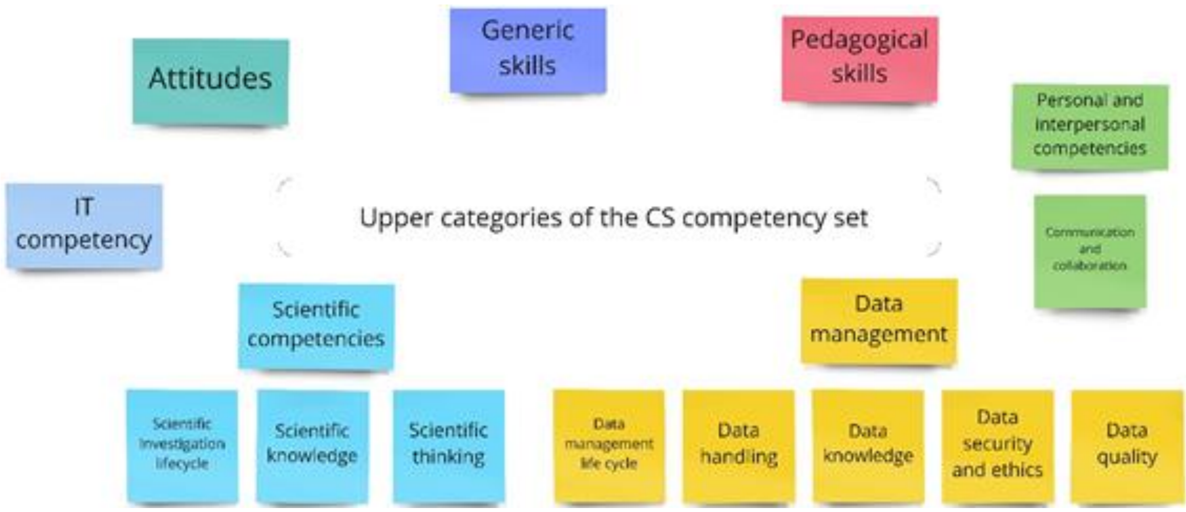


Figure 27: Results of competency clustering through the competency workshop based on the first version of the CS-DL-SL competency framework

4.3.2 Competency (Scheme) and Guideline

In this section, we describe how Citizen Science is and can be included in national curricula. As these differ strongly, we start with the comparison of each country's view on competencies.

Germany

In Germany, the curricula are relatively strictly defined. The curriculum defines areas of competency, content fields and competency expectations. In the following some definitions are provided (Ministerium für Schule und Bildung des Landes Nordrhein-Westfalen 2019, p.10):

Definition: **Areas of competency**____

> *"Areas of competence represent the basic dimensions of professional action. They serve to structure the individual sub-operations along the subject-specific cores and to clarify access for those involved in the teaching-learning process."* (Ministerium für Schule und Bildung des Landes Nordrhein-Westfalen 2019, p.10)

Definition: **Content fields**____

> *"Content areas systematize the following with their respective content focus the obligatory and indispensable subjects in comprehensive/secondary school lessons and provide indications for the content-related orientation of teaching and learning*." (Ministerium für Schule und Bildung des Landes Nordrhein-Westfalen 2019, p.10)

Definition: **Competency expectations**____

> "*Competency expectations bring together processes and objects and describe the subject-specific requirements and intended learning outcomes, which are to be bindingly achieved in two levels of progression*" (Ministerium für Schule und Bildung des Landes Nordrhein-Westfalen 2019, p.10)

Lithuania

General curricula for primary and general education established by Order of the Ministry of Education and Science of the Republic of Lithuania of 26 August 2007 (No ISAK-2433) is the guiding document for curricula development. The curriculum defines areas of competencies, content and expectations. The educational framework programmes define the content of education at national level. Schools and teachers use the framework to shape the content of education at school and classroom level, tailoring it to the needs of individual classes and pupils, so that pupils achieve to the best of their abilities.

At the end of the general education programme, students have acquired general competences:

- **The ability to learn**: (a) feels the need to learn and takes responsibility for his/her own learning, and perseveres in the pursuit of his/her goals; (b) is able to plan and reflect on the learning process and outcomes and to set reasonable follow-up objectives; (c) knows his/her preferred learning styles, sufficient and to-be-developed competences, and learning options;
- **Communication**: (a) seeks constructive dialogue and uses language responsibly; (b) understands and communicates a variety of verbal and non-verbal messages, and communicates according to the purpose, the addressee and the situation; (c) finds, critically evaluates, summarises information and presents it appropriately to others;
- **Cognitive**: (a) Seeks to know oneself, takes an interest in the social, cultural and natural environment and its development; (b) selects and applies cognitive methods in a purposeful manner, researches safely, thinks coherently, logically, critically, analyses and solves problems, and draws valid conclusions; (c) is able to describe the world in language, pictures, symbols, mathematical and other means;
- **Social**: (a) Respects and tolerates people of different cultures, genders, social and age groups, is aware of his/her own and others' rights and responsibilities, and understands himself/herself as a member of community and society; (b) Cooperates constructively towards a common goal, manages conflict, builds and maintains friendships, is empathetic and helps others;
- **Initiative and creativity**: (a) sees the connections between ideas and develops new ideas, thinks originally, applies experience to new situations, and anticipates alternative ways of solving problems; (b) open to change, unafraid of uncertainty, the unknown, reasonable risk, actively participates in the implementation of new ideas, involves others;
- **Personal**: (a) has a positive self-image, self-confidence and the ability to focus on achieving goals; (b) resilient to setbacks and conflicts, able to cope with stress, seek and accept support; (c) Acts honestly and responsibly, anticipates the consequences of his/her behavior, cares for his/her own health and the health of others, behaves safely and protects the environment.

At the end of the basic education programme, the pupil has acquired the foundations of the essential subject competencies necessary for life, further learning and work including: Moral Education, Languages, Mathematics, Natural Sciences, Social Education, Art education, Information and Communication Technologies, Technologies, Physical Education.

Italy

The **Ministry of education, university and research** in Italy establish a guideline in 2012 titled "*DM 245 - Indicazioni nazionali per il curricolo della scuola dell'infanzia e del primo ciclo d'istruzione" (National guideline for kindergarten and first cycle education curricula)* to define a framework for curriculum design which is a specific responsibility for each school. This framework is defined in respect of a regulation called "*Autonomia Scolastica*" (School Autonomy):

> *School autonomy is regulated by a special provision (Regulations) that defines its different ways of implementation.*
> *In addition to setting out criteria and procedures for teaching, organisational and management autonomy, the Regulation also gives indications on how each school must define its own Educational Offer Plan (POF - Piano dell'Offerta Formativa).*
> *The POF is defined as follows: the School Council gathers proposals and opinions, including from families, and decides on the general guidelines for the school's activities. On the basis of those general guidelines, the Teachers' Board draws up the POF, which is then officially adopted by the School Council. A copy of the POF is given to the parents when they enroll their children at the school (art. 3).*
> *Parents participate in the process of implementation and development of autonomy by assuming their responsibilities (art. 16).*

According to these principles the framework for curriculum design is an open text, which the professional community is invited to adopt and to contextualize, elaborating specific choices regarding contents, methods, organisation and evaluation consistent with the educational goals set out in the national document.

> *"The school curriculum is an expression of the teaching freedom of school autonomy and, at the same time, makes explicit the choices of the school community and the identity of the school. The construction of the curriculum is the process through which educational research and innovation are developed and organised. Each school prepares the curriculum within the Educational Offer Plan (POF) with reference to the student profile at the end of the first cycle of education, to the goals for the development of competences, to the specific learning objectives for each discipline.*
> *Starting from the school curriculum, teachers identify the most effective learning experiences, the most significant teaching choices, the most suitable strategies, with attention to the integration between disciplines and their possible aggregation into areas, as indicated by the regulation of school autonomy, which entrusts this task to school institutions.*

In order to promote meaningful learning and guarantee educational success for all pupils, the DM 245 also indicates, while respecting the autonomy of schools and the freedom of teaching, some methodological principles that distinguish effective educational action:

- Enhance pupils' experience and knowledge in order to root new content in it
- Implementing appropriate action on diversity to ensure that it does not become inequality
- Encourage exploration and discovery, in order to promote a desire to seek new knowledge
- Encourage collaborative learning, as the social dimension of learning plays a significant role
- Promote awareness of one's own way of learning, in order to 'learn to apprehend'
- Implement teaching activities in the form of laboratories, in order to encourage operability and, at the same time, encourage a dialogue and reflection on what is being done

Greece

General curricula from kindergarten up to upper secondary education (general and vocational upper secondary schools, daily and evening ones) are established by the Institute of Educational Policy on order of the Ministry of Education and Science (http://www.pi-schools.gr/) and acts as the guiding document for curricula development per grade and curriculum topic. The curriculum defines learning objectives, content (broader themes or suggested learning activities) as well as areas of competencies. The educational framework programmes define the content of education at national level and the number of teaching hours. In upper-secondary school there might be activities that are obligatory for all students or optional depending on the direction students will follow in the national exams they will take for progressing to Higher Education. Schools and teachers use the framework and the guidelines set in order to shape the content of education at classroom level, tailoring it to the needs of individual classes and students. If teachers want to engage students in further activities not included in the framework programme, they can do that in out of classroom clubs (after the end of the typical teaching hours programme). On top, there is a Cross-disciplinary Curriculum Programme for each of the different grades (primary & secondary) where Indicative Fundamental Concepts are addressed through an Interdisciplinary approach (Communication, Technology, Expression, Time-Space, Cooperation, Interaction). Curriculum Frameworks exist for the topics of Music, Foreign Language Learning, Home Economics, IT, Entrepreneurship Education, Technology, Science (Biology, Geology, Geography, Physics, Chemistry), Physical Education. Cross-disciplinary activities can be implemented in zones, Flexible Zone, Health Citizenship, Olympic Education, Environmental Education. Quite recently, the IEP introduced the Soft Skills Labs, in order to address the 21st century skills needed in the themes of Health Citizenship, Environmental citizenship, Social and civic citizenship (I care & act) and I Create and Innovate – Creative Thinking and Initiative, providing suggested educational content and activities, allowing for a little bit more of flexibility to teachers. In the curriculum framework competences (knowledge, skills and attitudes) to be acquired are presented from lower to higher levels of difficulty (basic knowledge acquisition up to metacognitive ones), personal/individual wellbeing/environmental literacy, initiative and creativity to social skills (communication/collaboration).

4.4 FabCitizen Competency Framework

In the following, we show the detailed descriptions of the competency framework. The framework was developed according to the methodology described in 4.1. In this section, we show the framework which has been validated and improved in several iterations.

As a starting point, we have categorized the competencies - initially, we have collected competencies of the fields of Citizen Science, Scientific Literacy and Data Science / Literacy. This lead to the following starting categories

Categories	**Subcategories**
Attitudes	Motivation Communication
Soft Skills	
Technology Use	
Skills of Scientific Inquiry / Investigation: **1. Identifying scientific issues and team formation** **2. Explain phenomena scientifically** **TODO: Aufteilung überarbeiten**	Methods of scientific investigation and a citizen science project: Receive, observe, organize questions Team creation Gain knowledge Development and testing of educational support materials Recruit and train participants Collect data Accept, edit and display data Analyze and interpret data test hypotheses use graphs and algebraic models when explaning interpret evidence and draw and communicate conclusions formulating a simple model make generalizations disseminate results
Domain-specific competencies	
Content, process and nature of scientific knowledge	
Understanding the scientific process	
Handling data - data collection, data representation, drawing conclusions	collecting, analyzing and interpreting data & scientific information Read and interpret graphical representations of data
Interest in world & science	

Economic, moral and ethical aspects of science	Ethics
Engagement in citizen science	civic engagement Measurable actions resulting from engagement in citizen science new participation 11. engages in science/technology for excitement and possible explanations.
Scientific inquiry	using technology collecting, analyzing and interpreting data & scientific information designing studies experimenting reasoning
Communication	communicate communicate conclusion
Scientific Investigation	research
Role Model	role model
Self-efficacy and self-confidence in science projects	Self-efficacy in relation to the participation in science projects Self-confidence to use science
Teaching	Teaching media Teaching methods (project-based, inquiry-based, context-based & discovery learning, STSE approach).
Knowledge of science related issues	Knowledge of science concepts and issues Knowledge of science vocabulary Knowledge of science-related issues Knowledge of the physical world Knowledge of the essential content of science, nature of science and the ability to distinguish it from non-science.
Scientific Inquiry - identify scientific issues	receive, observe and record questions gain knowledge search for information Design principles of science
Scientific Inquiry - explain phenomena scientifically	interpret and apply knowledge , test hypotheses, use graphs and algebraic models when explaining
Scientific Inquiry - use scientific evidence	make conclusions, formulate a simple model, make generalizations Formulate a simple model Make generalizations" Reflect on the social implications of the development of science and technology.

Understanding of scientific process	Understanding of the scientific process
Attitudes	Awareness, appreciation of science
Apply scientific knowledge (to solve problems)	PD3. Apply science for social purposes Ability to apply scientific knowledge in solving problems Apply scientific knowledge to a given situation
Scientific Communication	PD4. Decode & encode scientific communications
Basic skills	Understand and interpret basic standards
Reflection about science & technology	14. recognizes the strengths and limitations of science and technology for advancing human welfare
Using tools	PD13. Use some of the tools of science
Relations between science, technology and society	CD 14. Relations between science, technology and society CD12. Relations between science and society CD13. Relationships science to technology
Scientific Argumentation	defends decisions and actions using rational argument based on evidence; and Identify a valid scientific argument PD7. Reason and argue
Information Issues	Evaluation of the use and misuse of scientific information distinguish information quality locates, collects, analyses, and evaluates sources of scientific and technological information and uses these sources in solving problems, making decisions, and taking actions

Based on this initial competencies, competencies were derived. Additionally, the competency levels were defined for the roles (teacher / students) and grades addressed.

The following table shows the full competency framework.

Category	Description	Operational description	Secondary school I, Grade 5-6	Secondary school I, Grade 7-10	Teachers	Reference
Data Interpretation						
	Read & interpret data	I am able to read and interpret data.	Ability to read and interpret data / graphical representations of statistical surveys	Ability to read and interpret data / graphical representations of statistical surveys	Ability to read and interpret data / graphical representations of statistical surveys	Physics + Mathematics Curriculum
	Read and interpret graphical representations of data					
Data Cleaning						
	Clean Data	I am able to clean up data.	Ability to identify outliers	Ability to clean up data.	Ability to clean up data.	Mathematics Curriculum
Data Transformation						
	Data Representation and Transformation (into information)	I am able to transform data into information and to transform information into decisions to drive data-driven decision making.	/	Ability to process information from intra- or extra-informational contexts in appropriate, formalised structures and represent them through data.	Ability to process information from intra- or extra-informational contexts in appropriate, formalised structures and represent them through data.	Computer Science Curriculum
	Transform information into decision					
	Data-driven decision making					
Data Evaluation						

	Evaluate decisions based on data (&sources)	I am able to evaluate decisions based on data, to evaluate outcomes , to interpret data and to use data tools for data evaluation.	Ability to evaluate data and interpret data (trends, structure, relations)	Ability to evaluate data and interpret data (trends, structure, relations)	Ability to evaluate data and interpret data (trends, structure, relations)	Physics Curriculum
	Evaluate outcomes					
	Interpret data					
	Data Tools					
Scientific Investigation Questions						
	Ask Question / Define	I am able to ask and to define questions	Ability of recognition of problems and formulation of questions	Ability of recognition of problems and formulation of questions	Ability of recognition of problems and formulation of questions	Computer Science Curriculum
	Identifying & ask scientific questions	I am able to identify and to ask scientific questions.	Ability to identify and ask scientific questions.	Ability to identify and ask scientific questions.	Ability to identify and ask scientific questions.	Physics Curriculum
	Recognition of Scientific Issues	I am able to recognize scientific issues.	Ability to recognize scientific issues	Ability to recognize scientific issues	Ability to recognize scientific issues	New (own) formulation
Communicating with data						
	Communicating and presenting effectively with data	I am able to communicate and present data effectively.	Ability to present column and bar charts.	Ability to present and communicate different charts and easy statistics (median, mean ...).	Ability to present different charts and statistics.	Mathematics Curriculum
	Data Presentation					
Critical thinking						
	Critical thinking					

	Verify data / apply critical thinking	I am able to apply critical thinking and to verify data.	Ability to critically assess the significance of representational and work tools for answering questions and examine their relevance for opening up the spatial reality of life	Ability to critically assess the significance of representational and work tools for answering questions and examine their relevance for opening up the spatial reality of life	Ability to critically assess the significance of representational and work tools for answering questions and examine their relevance for opening up the spatial reality of life	Geography Curriculum
Critical Thinking	Critical thinking	I am able to think critically	Ability to think critically (about science and to deal with scientific expertise)	Ability to think critically (about science and to deal with scientific expertise)	Ability to think critically (about science and to deal with scientific expertise)	New (own) formulation
Data Access						
	Get / Access data	I am able to access data.	Ability to extract data from analog and digital media offerings.	Ability to extract data from analog and digital media offerings.	Ability to access data	Chemistry & Physics Curriculum
Data Analysis						
	Using data analytics (data analysis)	I am able to apply statistics as e.g trend analysis and do predictions, distinguish between correlation and causality and I am able to analyze data and find insights from data.	Ability to evaluate data and interpret data (trends, structure, relations)	Ability to evaluate data and interpret data (trends, structure, relations)		Physics Curriculum
	Analysis of (classroom) data					
	Trend analysis / Predictions					

Data Application						
	Specify data application	I am able to specify and to identify data applications.	/	Ability to identify and explain data types, attributes and attribute values of objects in selected applications and document them using suitable forms of representation.	Ability to identify and explain data types, attributes and attribute values of objects in selected applications and document them using suitable forms of representation.	Computer Science Old Curriculum
	Identify data application					
Data Collection						
	Discovery & acquisition of data	I am able to discover, acquisite and collect data.	Ability to use data from media offerings (print media, Internet and formulary) for research	Ability to use data from media offerings (print media, Internet and formulary) for research	Ability to use data from media offerings (print media, Internet and formulary) for research	Mathematics Curriculum
	Data Collection					
	Data Discovery and Collection		Ability to collect data	Ability to collect data	Ability to collect data	
Handling data - data collection, data representation, drawing conclusions.	collecting, analyzing and interpreting data & scientific information	I am able to collect, analyze and to interpret data and scientific information	Ability to read and interpret data / graphical representations of statistical surveys	Ability to read and interpret data / graphical representations of statistical surveys	Ability to read and interpret data / graphical representations of statistical surveys	Physics + Mathematics Curriculum
Data Conversion						
	Data Conversion	I am able to converse data	Ability to encode data for processing with an informatics system (DI),	Ability to encode data for processing with an informatics system (DI),	Ability to encode data for processing with an informatics system (DI),	Computer Science Curriculum

Data Culture						
	Establish data culture	I am able to establish data culture.	/(not found)	/(not found)	/(not found)	
	Data Culture					
data ethics / privacy						
	personal data	I am aware of data ethics, privacy and that personal data must be protected.	Ability To deal responsibly with personal and Dealing with other people's data; data protection, Ability to respect privacy and information security	Ability To deal responsibly with personal and Dealing with other people's data; data protection, Ability to respect privacy and information security	Ability To deal responsibly with personal and Dealing with other people's data; data protection, Ability to respect privacy and information security	Medienkompetenzrahmen
	privacy					
	Data ethics & Security					
Data Evaluation						
	learning from data	I am able to evaluate data and to evaluate decisions based on data and to use data tools for data evaluation.	Ability to evaluate data.	Ability to evaluate data.	Ability to evaluate data.	Chemistry + Physics Curriculum
	Evaluate decisions based on data (&sources)					
	Evaluate outcomes					
	Data Tools					
Data Gathering						
	Finding / obtaining data	I am able to find and obtain data.	I am able to find and obtain online data.	I am able to finde and obtain online data in different search engines.	I am able to finde and obtain online data in different search engines.	
Data Interpretation						

	Interpret data	I am able to interpret data.	Ability to interpret a column and a bar chart.	Ability to interpret data.	Ability to interpret data.	Mathematics Curriculum + Computer Science Curriculum
Data Management						
	techniques for managing big data	I am able to use techniques of data management, as for example data sharing, data organization, data providing, share data, curate data and giving access to data.	Ability to store, retrieve and retrieve data securely from different locations; ability to summarise, organise and store data in a structured way.	Ability to store, retrieve and retrieve data securely from different locations; ability to summarise, organise and store data in a structured way.	Ability to store, retrieve and retrieve data securely from different locations; ability to summarise, organise and store data in a structured way.	Medienkompetenzrahmen
	Data Sharing					
	Creating (meta)-data)					
	Managing data / Data Management					
	Data organization					
	Provide data					
	Data curation and reuse					
	Data Management					
	Governing / giving access					
Data Manipulation						
	Data Manipulation	I am able to manipulate data.	/ not found	/ not found		
Data Processing						
	Clean Data	I am able to process data, e.g. clean, interact with, link,	/ not relevant	Ability to process similar data with the help of a suitable tool	Ability to process similar data with	Computer Science Curriculum
	Process data					

	Reading data	read and standardise data.			the help of a suitable tool	
Data Quality						
	Evaluate (quality of) data	I am aware that quality insurance is an important topic and I am able to evaluate and ensure the quality of data.	Ability to recognise and critically evaluate data and their sources, as well as the strategies and intentions behind them.	Ability to recognise and critically evaluate data and their sources, as well as the strategies and intentions behind them.	Ability to recognise and critically evaluate data and their sources, as well as the strategies and intentions behind them.	Medienkompetenz rahmen
	Quality insurance					
	Evaluating and Ensuring Quality					
Data Security						
	Security	I aware of security issues e.g. data security.	/ too early	Ability to describe the threat to data from defects and malware and name measures to protect data	Ability to be aware of security issues.	Computer Science Curriculum
Data storage						
	systems for managing / storing data	I am able to store data and to use systems for manaaging and storing data and I know the function principles of data stores.	Ability to store data	Ability to store data.	I am able to store data (e.g. excel) file and I know different cloud systems for data storage.	Computer Science Curriculum
	Preserve data					
	Data storage					
	systems for storing big data					
	function principles of data stores					
Data Transformation						

	Data Conversion and Interoperability	I am able to convert data, to transform data into information and to transform information into data.	/ too early	Ability to process information from internal or information contexts into appropriate, formalised structures and represent them through data.	Ability to process information from internal or information contexts into appropriate, formalised structures and represent them through data.	Computer Science Curriculum
	Data Representation and Transformation (into information)					
Data Understanding						
	Understanding data (used in business contexts)	I am able to understand data used in business contexts.	/	/		
Data Use						
	Using data	I am able to use data.	Ability to use data	Ability to use data	Ability to use data	Mathematics Curriculum
Data Visualization						
Scientific Investigation - Graph and models	Use graphs and algebraic models when explaining	I am able to visualize data and to use graphs and algebraic models when explaining scientific phenomena.	Ability to visualize data with linguistic, mathematical and pictorial means of representation	Ability to visualize data with linguistic, mathematical and pictorial means of representation	Ability to visualize data with linguistic, mathematical and pictorial means of representation	Physics Curriculum
	Visualize data / create graphical representations					
	Visualizing data	I am able to visualize data.	Ability to visualize data with bar and column charts.	Ability to visualize data with linguistic, mathematical and pictorial means of representation	Ability to visualize data with linguistic, mathematical and pictorial means of representation	Mathematics curriculum & physics curriculum
Databases & data formats						
	Databases & data formats	I know different databases and data formats.	/ too early	Ability to choose suitable data types & ability to store data	Ability to choose suitable data types & ability to store data	Computer Science Curriculum

Decision making						
	Data-driven decision making	I am able to make data-driven decision making.	/	/		
Design Principles						
	Cultures of practice	I am able to apply design principles.	/	/		
Generate Questions						
	Generate questions (about their learning in classes)	I am able to generate questions.	Ability to ask questions about a given problem situation	Ability to generate /ask questions about issues	Ability to generate /ask questions about issues	Mathematics + Computer Science Curriculum
Identify problems						
	Identify problems using data	I am able to identify problems using data.	Ability to interpret results of a data processing process	Ability to interpret results of a data processing process	Ability to interpret results of a data processing process	Mathematics Curriculum
			Ability to express problem situations in own words	Ability to express problem situations in own words	Ability to express problem situations in own words	Mathematics Curriculum
Data Interpretation						
	Interpret results	I am able to interpret results und to develop inferences.	Ability to relate elaborated solutions to the real situation and interpret them as an answer to the question	Ability to interpret results of a data processing process	Ability to interpret results of a data processing process	Computer Science + Mathematics Curriculum

	Develop inferences & explanations		Ability to read and interpret graphical representations of statistical surveys.			
representing data on physical level						
	representing data on physical level	I am able to represent data on physical level.	/ not found	Ability to explain the logical and arithmetic operation of computer systems based on the binary system.	Ability to explain the logical and arithmetic operation of computer systems based on the binary system.	Computer Science Curriculum
Engagament in citizen science	civic engagement Measurable actions resulting from engagement in citizen science new participation 11. engages in science/technology for excitement and possible explanations.	I am able to engage and participate in citizen science.	Ability to engage and participate in citizen science projects.	Ability to engage and participate in citizen science projects	Ability to engage and participate in citizen science projects	New (own) formulation

Use science, ethics, solving problems, making decisions	uses concepts of science and of technology, as well as an informed reflection of ethical values, in solving everyday problems and making responsible decisions in everyday life, including work and leisure;	I use concepts of science and technology for solving problems.	Ability to use concepts of science and technology for problem solving	Ability to use concepts of science and technology for problem solving	Ability to use concepts of science and technology for problem solving	New (own) formulation
Think scientifically	Ability to think scientifically	I am able to think scientifically.	Ability to think scientifically	Ability to think scientifically	Ability to think scientifically	New (own) formulation
Internet use	Use of the Internet	I am able to use the internet	Ability to use the internet.	Ability to use the internet.	Ability to use the internet.	Computer Science Old Curriculum
Use Scientific Evidence	use scientific evidence	I am able to use scientific evidence	Ability to use scientific evidence	Ability to use scientific evidence	Ability to use scientific evidence	New (own) formulation
Scientific inquiry - using technology+	using technology	I am able to use technology	Ability to use technology	Ability to use technology	Ability to use technology	New (own) formulation
Communication	communicate communicate conclusions	I am able to communicate in the scientific inquiry process and I am able to communicate conclusions.	Ability to present facts in an appropriate manner orally and in writing using technical terms.	Ability to present facts in an appropriate manner orally and in writing using technical terms.	Ability to present facts in an appropriate manner orally and in writing using technical terms.	Computer Science Curriculum
Scientific inquiry - Designing studies	designing studies	I am able to design studies	Ability to participate in designing studies in class	Ability to participate in designing studies in class	Ability to participate in designing studies in class	New (own) formulation
Evaluation of the validity of sources	Evaluate the validity of sources	I am able to evaluate the validity of sources.	Ability to evaluate the validity of sources.	Ability to evaluate the validity of sources.	Ability to evaluate the validity of sources.	New (own) formulation

Scientific inquiry - Experiment	experimenting	I am able to conduct an experiment.	Ability to conduct qualitative and simple quantitative experiments and investigations through	Ability to conduct qualitative and simple quantitative experiments and investigations through	Ability to conduct qualitative and simple quantitative experiments and investigations through	Physics Curriculum
Scientific inquiry	reasoning / argumentation	I am able to reason / to argument.	Ability to represent their own or other positions argumentatively coherent	Ability to represent their own or other positions argumentatively coherent	Ability to represent their own or other positions argumentatively coherent	Geography Curriculum
Scientific Investigation - Research	Research skills (knowledge & skill, attitude, ethics) to find information	I am able to apply research skills to find information	Ability to research in libraries and on the Internet in order to obtain information	/	Ability to research in libraries and on the Internet in order to obtain information	Geography Curriculum
Role Model	Role model of the teacher	I am able to act as a role model as a teacher.	/	/	Ability to act like a role model	New (own) formulation
Self-efficacy in science projects	Self-efficacy in relation to the participation in science projects Self-confidence to use science	I am self-confidence to use science and I have got self-efficacy in relation to the participation in science projects.	Ability to have self-confidence to use science.	Ability to have self-confidence to use science.	Ability to have self-confidence to use science.	New (own) formulation
Scientific inquiry	Skills of scientific inquiry (procedural skills)	I have got the skills of scientific inquiry	/	Ability to understand the process of scientific thinking and working	Ability to understand the process of scientific thinking and working	Chemistry Curriculum
Scientific inquiry	synthesizing	I am able to synthesize results	Ability to synthesize results	Ability to synthesize results	Ability to synthesize results	

Teaching media	Teaching media	I am able to teach media.	/	/	Ability to teach media	New (own) formulation
Teaching methods	Teaching methods (project-based, inquiry-based, context-based & discovery learning, STSE approach).	I am able to apply different teachings methods as (project-based, inquiry-based and other learning approaches).	/	/	Ability to apply different teaching methods	New (own) formulation
Understanding of scientific process	Understanding of the scientific process and how science is done	I am able to understand the scientific process.	Ability to understand the scientific process.	Ability to understand the scientific process.	Ability to understand the scientific process.	Chemistry Curriculum
Independent work	Independence in learning science Self-learning science	I am able to learn science independently.		Ability to learn [...] independently Ability to independently plan, conduct and evaluate experiments	Ability to learn [...] independently Ability to independently plan, conduct and evaluate experiments	Computer Science + Physics Curriculum
Interest in world & science	Interest to science / environment related topics	I am interested in science and world-related topics.	Interest in science and world-related topics	Interest in science and world-related topics	Interest in science and world-related topics	New (own) formulation
Knowledge of science-related issues	Knowledge of the essential content of science, nature of science and the ability to distinguish it from non-science.	I have got knowledge of the essential content of science.	Knowledge of science-related issues	Knowledge of science-related issues		New (own) formulation
	PD3. Apply science for social purposes		Ability to integrate facts / knowledge into problem	Ability to integrate facts / knowledge into	Ability to integrate facts / knowledge into	Physics Curriculum

Apply scientific knowledge (to solve problems)	Ability to apply scientific knowledge in solving problems Apply scientific knowledge to a given situation	I am able to apply scientific knowledge in solving problems	contexts, develop solution strategies and apply these where possible.	problem contexts, develop solution strategies and apply these where possible.	problem contexts, develop solution strategies and apply these where possible.	
Apprecation of science	AD1. Appreciation for science	I appreciate science	Appreciation of science	Appreciation of science	Appreciation of science	New (own) formulation
Awareness of science	the nature of science, including its relationship to culture and its applications 12. recognizes that science and technology are human endeavors;	I am aware of the imperfection and nature of science.	Awareness of the imperfection and nature of science	Awareness of the imperfection and nature of science	Awareness of the imperfection and nature of science	New (own) formulation
Scientific Communication	PD4. Decode & encode scientific communications	I am able to decode and encode scientific communication.	Ability to exchange scientific knowledge and its applications using appropriate technical language	Ability to exchange scientific knowledge and its applications using appropriate technical language	Ability to exchange scientific knowledge and its applications using appropriate technical language	Physics Curriculum
Decision Making	PD9. Take decisions	I am able to take decisions.	Ability to lead decisions on the basis of subject-related discussions	Ability to lead decisions on the basis of subject-related discussions	Ability to lead decisions on the basis of subject-related discussions	Mathematics Curriculum
Design principles of science	CD4. Broad principles of science	I know the broad principles of science.	Knowledge of the broad principles of science (physical / chemical ...)	Knowledge of the broad principles of science (physical / chemical ...)	Knowledge of the broad principles of science (physical / chemical ...)	Chemistry & Physics Curriculum
Distinguish information quality	distinguishes between scientific and technological evidence and personal opinion and between reliable and unreliable information;	I am able to distinguish between information quality.	/ not found	Ability to independently filter information from analogue and digital media offerings, analyse them in terms of their relevance, quality, usefulness and intention,	Ability to independently filter information from analogue and digital media offerings, analyse them in terms of their relevance, quality,	Chemistry Curriculum

					usefulness and intention,	
	engages in responsible personal and civic actions after weighing the possible consequences of alternative options.	I am able to engage in responsible personal and civic actions after weighing the possible consequences of alternative options	Ability to weigh up criteria regarding use, economy, recyclability and environmental compatibility using the example of a (chemical) product.	Ability to weigh up criteria regarding use, economy, recyclability and environmental compatibility using the example of a (chemical) product.	Ability to weigh up criteria regarding use, economy, recyclability and environmental compatibility using the example of a (chemical) product.	Chemistry Curriculum
	weighs the benefits/burdens of scientific and technological development;					
Economic, moral and ethical aspects of science	considers the political, economic, moral and ethical aspects of science and technology as they relate to personal and global issues.	I am able to consider political , economic and moral aspects of science.	Ability to consider ethical, political, ecological and economic aspects of science.	Ability to consider ethical, political, ecological and economic aspects of science.	Ability to consider ethical, political, ecological and economic aspects of science.	Chemistry & Physics Curriculum
Evaluation of the use and misuse of scientific information	Evaluate the use and misuse of scientific information	I am able to evaluate the use and misuse of scientific information.	Ability to independently analyse information in terms of their relevance, quality, usefulness and intention,	Ability to independently analyse information in terms of their relevance, quality, usefulness and intention,	Ability to independently analyse information in terms of their relevance, quality, usefulness and intention,	Chemistry Curriculum
	explain phenomena scientifically Explain or interpret phenomena scientifically and predict change	I am able to explain phenomena scientifically and to predict change.	Ability to analyse and interpret phenomena and facts	Ability to analyse and interpret phenomena and facts	Ability to analyse and interpret phenomena and facts	Chemistry & Physics Curriculum
	Explaining phenomena scientifically					
Explain phenomena scientifically	offers explanations of natural phenomena testable for their validity;					

Gain scientific knowledge	CD8. The attempt of scientific / technological knowledge	I am able to gain scientific knowledge	Ability to gain scientific knowledge	Ability to gain scientific knowledge	Ability to gain scientific knowledge	New (own) formulation
Information Management for solving problems & making decisions	locates, collects, analyses, and evaluates sources of scientific and technological information and uses these sources in solving problems, making decisions, and taking actions	I am able to manage information and to evaluate sources of scientific and technological information.	Ability to independently analyse information in terms of their relevance, quality, usefulness and intention, and take decisions	Ability to independently analyse information in terms of their relevance, quality, usefulness and intention, and take decisions	Ability to independently analyse information in terms of their relevance, quality, usefulness and intention, and take decisions	Chemistry + Mathematics Curriculum
Integration of knowledge	PD11. Integrate knowledge	I am able to integrate knowledge.	Ability to integrate knowledge	Ability to integrate knowledge	Ability to integrate knowledge	New (own) formulation
Interest in world & science	8. displays curiosity about the natural and human-made world; 9. values scientific research and technological problem solving; AD3. Inclination to stay up to date Appreciation of and familiarity with science, including their sense of wonder and curiosity	I am interested in the world and science and I like to stay up to date.	Interest in the world and science	Interest in the world and science	Interest in the world and science	New (own) formulation
Interpretation of scientific evidence	Interpret scientific evidence and draw and communicate conclusions	I am able to interpret scientific evidence and to draw and communicate conclusions.	Ability to interpret, evaluate and present experimental results in a subject-specific manner.	Ability to interpret, evaluate and present experimental results in a subject-specific manner.	Ability to interpret, evaluate and present experimental results in a subject-specific manner.	Chemistry Curriculum
Judging	PD8. Judge the validity of claims	I am able to judge the validity of claims.	Ability to judge the validity of claims	Ability to judge the validity of claims	Ability to judge the validity of claims	New (own) formulation
Justify inferences, predictions and conclusions	Justify inferences, predictions and conclusions based on quantitative data	I am able to justify inferences, predictions and conclusions.	// too early	Ability to justify inferences, predictions and conclusions based on quantitative data	Ability to justify inferences, predictions and conclusions based on quantitative data	New (own) formulation

Knowledge of science concepts and issues	CD1. Science concepts CD10. Science and technology are human efforts CD9. Science is a social activity	I know science concepts and that science and technology are human efforts and that science is a social activity.	Knowledge of basic science concepts	Knowledge of science concepts	Knowledge of science concepts	Chemistry & Physics Curriculum
Knowledge of science vocabulary	CD3. Science vocabulary	I am able to communicate with science vocabulary.	Ability to use simple elements of technical language in appropriate forms of presentation.	Ability to use elements of technical language in appropriate forms of presentation.	Ability to use elements of technical language in appropriate forms of presentation.	Chemistry Curriculum
Knowledge of science-related issues	Knowledge necessary for intelligent participation in science-based issues Knowledge of what is considered science Knowledge of the risks and benefits of science	I have got knowledge for participations in science-based issues and I am aware of the risks and benefits of science.	Ability to use physical knowledge to evaluate opportunities and risks of science-based issues	Ability to use physical knowledge to evaluate opportunities and risks of science-based issues	Ability to use physical knowledge to evaluate opportunities and risks of science-based issues	Physics Curriculum
Knowledge of the physical world	CD2. The physical world	I have got knowledge of the physical world.	Knowledge of the physical world	Knowledge of the physical world	Knowledge of the physical world	New (own) formulation
Monitoring of study	AD4. Inclination to monitor and act on SRSP*	I am able to monitor studies.	Ability to monitor studies	Ability to monitor studies	Ability to monitor studies	New (own) formulation
Read & interpret data	Read and interpret graphical representations of data	I am able to read and interpret graphical representations of data.	Ability to read and interpret graphical representations of statistical survey / data.	Ability to read and interpret graphical representations of statistical survey / data.	Ability to read and interpret graphical representations of statistical survey / data.	Mathematics + Physics Curriculum
Relations between science, technology and society	CD 14. Relations between science, technology and society CD12. Relations between science and society	I know the relations between science and society and between	Ability to identify scientific-technical facts and contexts and to describe social relations.	Ability to identify scientific-technical facts and contexts and to	Ability to identify scientific-technical facts and contexts	Chemistry Curriculum

	CD13. Relationships science to technology	science and technology.		describe social relations.	and to describe social relations.	
Relations of science & history	16. connects science and technology to other human endeavors e.g. history, mathematics, the arts, and the humanities; and	I am able to connect science and technology to other human endeavors.	Ability to connect science and technology to other subjects or historical relations	Ability to connect science and technology to other subjects or historical relations	Ability to connect science and technology to other subjects or historical relations	Physics Curriculum
Scientific Argumentation	defends decisions and actions using rational argument based on evidence; and Identify a valid scientific argument PD7. Reason and argue	I am able to identify a valid scientific argument and to defend decisions and actions using rational arguments based on evidence.	Ability to argue in a fact-based, rational and coherent manner on the basis of scientific knowledge and scientific ways of thinking.	Ability to argue in a fact-based, rational and coherent manner on the basis of scientific knowledge and scientific ways of thinking.	Ability to argue in a fact-based, rational and coherent manner on the basis of scientific knowledge and scientific ways of thinking.	Chemistry Curriculum
	Formulate a simple model	I am able to use techniques of scientific evidence, as for example formulating a simple model, making generalizations and to reflect on the social implications of the development of science and technology.	Ability to illustrate, explain and predict scientific processes and phenomena with given models and to distinguish models from reality.	Ability to illustrate, explain and predict scientific processes and phenomena with given models and to distinguish models from reality.	Ability to illustrate, explain and predict scientific processes and phenomena with given models and to distinguish models from reality.	Chemistry Curriculum
	Make generalizations"		Ability to generalize results	Ability to generalize results	Ability to generalize results	Chemistry Curriculum
Scientific Evidence	Reflect on the social implications of the development of science and technology.		Ability to name and assess aspects of the effects of the application of scientific knowledge and methods in social contexts using selected examples.	Ability to name and assess aspects of the effects of the application of scientific knowledge and methods in social contexts using selected examples.	Ability to name and assess aspects of the effects of the application of scientific knowledge and methods in social contexts using selected examples.	Physics Curriculum
Scientific Evidence - Draw conclusions	draw and communicate conclusion					Physics Curriculum

	Draw conclusions	I am able to draw and to communicate conclusions.	Ability to draw and to communicate conclusions.	Ability to draw and to communicate conclusions.	Ability to draw and to communicate conclusions.	
Scientific Inquiry	PD12. Engage in inquiry Scientific inquiry	I am able to engage in inquiry.	Ability to think and work scientifically - to understand scientific knowledge in simple steps and to question it constructively	Ability to think and work scientifically - to understand scientific knowledge in simple steps and to question it constructively	Ability to think and work scientifically - to understand scientific knowledge in simple steps and to question it constructively	Chemistry Curriculum
Scientific Investigation	Learning the main features of a scientific investigation	I know the main features of a scientific investigation	Ability to learn the main features of a scientific investigation	Ability to learn the main features of a scientific investigation	Ability to learn the main features of a scientific investigation	New (own) formulation
	Interpret and apply knowledge	I am able to interpret and to apply knowledge.	Ability to interpret and to apply knowledge	Ability to interpret and to apply knowledge	Ability to interpret and to apply knowledge	New (own) formulation
Scientific Investigation - Graph and models	Use graphs and algebraic models when explaining Visualize data / create graphical representations	I am able to visualize data and to use graphs and algebraic models when explaining scientific phenomena.	Ability to visualize data with linguistic, mathematical and pictorial means of representation	Ability to visualize data with linguistic, mathematical and pictorial means of representation	Ability to visualize data with linguistic, mathematical and pictorial means of representation	Physics Curriculum
Scientific Investigation - Hypothesis	Test hypotheses	I am able to test hypotheses.	Ability to test hypotheses	Ability to test hypotheses.	Ability to test hypotheses.	Chemistry & Physics Curriculum
Scientific Investigation - Interpreting evidence	Identify the correct description, explanation, and prediction	I am able to identify the correct description, explanation and prediction.	Ability to describe and explain the meaning of texts	Ability to describe and explain the meaning of texts	Ability to describe and explain the meaning of texts	Physics Curriculum
Scientific Investigation - Questions	Recognition of Scientific Issues	I am able to recognize scientific issues.	Ability to recognize scientific issues	Ability to recognize scientific issues	Ability to recognize scientific issues	New (own) formulation
Scientific Investigation - Questions	Record, observe, and organize questions	I am able to rescord, observe and to organize questions.	Ability to recognise and develop questions	Ability to recognise and develop questions	Ability to recognise and develop questions	Physics Curriculum

Scientific Investigation - Research	Identifying key words to find scientific information	I am able to identify key words to find scientific information.	Ability to identify keywords to find scientific information	Ability to identify keywords to find scientific information	Ability to identify keywords to find scientific information	New (own) formulation
Scientific Investigation - Research	Becoming familiar with topics that can be investigated scientifically	I am familiar with topics which can be investigated scientifically	Being familiar with topics that can be investigated scientifically	Being familiar with topics that can be investigated scientifically	Being familiar with topics that can be investigated scientifically	New (own) formulation
Scientific Investigation- Analyse & interpretation outomes of studies	analyses interactions among science, technology and society.	I am able to analyze interactions among science, technology and society.	Ability to recognize and to evaluate economical, social and political connections of technology	Ability to recognize and to evaluate economical, social and political connections of technology	Ability to recognize and to evaluate economical, social and political connections of technology	Physics Curriculum
Solving problems	Solve problems using quantitative skills including probability and statistics solving problems	I am able to solve problems	Ability to select appropriate terms, contexts, procedures, media and tools for problem solving	Ability to select appropriate terms, contexts, procedures, media and tools for problem solving	Ability to select appropriate terms, contexts, procedures, media and tools for problem solving	Mathematics Curriculum
Strengths & limitations of science & technology	14. recognizes the strengths and limitations of science and technology for advancing human welfare	I recognize the strengths and limitations of science and technology.	Ability to use physical knowledge to evaluate opportunities and risks in selected examples of modern technologies.	Ability to use physical knowledge to evaluate opportunities and risks in selected examples of modern technologies.	Ability to use physical knowledge to evaluate opportunities and risks in selected examples of modern technologies.	Physics Curriculum
Using tools	PD13. Use some of the tools of science	I am able to use tools of science.	Ability to use tools of science	Ability to use tools of science	Ability to use tools of science	New (own) formulation
Understanding of scientific process	elements of research design and how they impact scientific findings / conclusions	I understand the elements of research design and how they impact scientific findings / conclusions.	Ability to understand the elements of research design and how they impact scientific findings / conclusions	Ability to understand the elements of research design and how they impact scientific findings / conclusions	Ability to understand the elements of research design and how they impact scientific findings / conclusions	New (own) formulation

	Understand methods of inquiry	I am able to understand the method of inquiry and the scientific process as such.	Ability to understand the method of inquiry and the scientific process as such	Ability to understand the method of inquiry and the scientific process as such	Ability to understand the method of inquiry and the scientific process as such	New (own) formulation
Understanding standards	Understand and interpret basic standards	I am able to understand and to interpret basic standards.	Ability to understand and to interpret basic standards	Ability to understand and to interpret basic standards	Ability to understand and to interpret basic standards	New (own) formulation
Using science	PD2. Use science in everyday life	I am able to use science in everydaylife.	Ability to use science in everydaylife	Ability to use science in everydaylife	Ability to use science in everydaylife	New (own) formulation
Critical Thinking	Critical thinking	I am able to think critically	Ability to think critically (about science and to deal with scientific expertise)	Ability to think critically (about science and to deal with scientific expertise)	Ability to think critically (about science and to deal with scientific expertise)	New (own) formulation

This framework is a basis for the developing competencies in the related areas. It is clear that not all competencies will be addressed in a single course or project. As a next step, we will provide guidance how to use the framework in schools. Part of this process is the mapping to national curricula or in other words: how to embed CS projects and competencies in different subjects.

4.5 Competency Mapping

In this section, we provide guidance in which subject areas Citizen Science and our corresponding competencies can be implemented in line with the national curricula.

4.5.1 Germany

To identify citizen science competencies in school curricula, the curricula for physics, chemistry, computer science, maths and geography have been analyzed and the approach was to identify overlaps with citizen science and scientific literacy competencies and data literacy. In the following the analysis table is provided (Table 2).

Found competencies in the curricula	Physics curriculum	Chemistry curriculum	Computer science curriculum	Geography curriculum	Math curriculum	Citizen Science / Scientific Literacy	Data Literacy
Using models to illustrate (chemical) phenomena		X				X	
Extract information and data from analogy and digital media offerings, reproduce their key messages, and note the source (information processing).	X	X				X	X
Representation and interpretation	X		X			X	
Communicate and cooperate	X		X			X	
Selection of data and information, testing for relevance and reliability	X					X	
Evaluation of the hypotheses	X					X	
Interpretation of data, (trends, structure and relations)	X						X
Visualization of data with linguistic, mathematical and pictorial means of representation	X						X

Read & interpret data	X						X
Clean Data					X		X
Data Transformation			X				X
Data Presentation					X		X
Data Analysis	X						X
Explain phenomena scientifically	X	X				X	
Knowledge of science concepts	X	X				X	
Problem solving					X	X	
Scientific communication	X					X	

Table 2: Overlapping competencies in the curricula (Germany)

Our analysis shows that there are many overlapping competencies - therefore, it is easy for teachers to use CS projects as part of cross-subject learning and teaching.

4.5.2 Lithuania

To identify Citizen Science competencies in school curricula, the programmes for Technologies, Information and Communication Technologies and Natural Sciences have been analyzed to identify overlappings with Citizen Science and Scientific literacy competencies. The programmes of Natural Science, Information and Communication technologies and Technologies have the most potential to include Citizen Science activities:

- **Natural Science** education programme is designed to develop pupils' scientific competence - the ability and willingness to use the knowledge and methods of natural inquiry to answer questions, to seek evidence-based conclusions and solutions; to understand the changes in the natural world caused by human activity; and to take personal responsibility for preserving the environment and protecting their own health and that of other people. The natural science education of pupils is based on knowledge of the natural sciences: biology, chemistry, physics and astronomy. The subject of geography is also linked to this area of education. In addition, pupils are helped to develop healthy lifestyles and environmental skills, and to understand that knowledge of natural sciences has a significant impact on the social, political and economic life of humanity.

- **Technologies** programme designed with the goal for the pupils to understand, use, evaluate and manage technology, as well as positive attitudes towards the continuous development of technology, is important for modern society, and therefore technological education is perceived as an integral part of the creative and productive process. The aim is to develop a technologically literate, inquisitive, reflective, creative, proactive and responsible personality. Technology education is an integral part of holistic education, enabling students to become technologically literate, able to acquire new knowledge and develop technological skills on a continuous basis, and to understand, use and appreciate the continuous development of technology in the creative/practical process, by forming a positive attitude towards the transformation of technology in the context of the past, present and future. The purpose of technology education is to develop general and technological technological and technological competences - the body of knowledge and understanding, skills and attitudes that enable the student to acquire the foundations of technological literacy necessary for every human being in a constantly changing socio-cultural environment.
- The purpose of **Information and Communication Technologies** programme in general education is to develop students' information and technological competences. Information technology has several missions: firstly, applied - to develop students' abilities and skills in the skilful use of computer tools for effective and enjoyable learning in all subjects; secondly, cognitive - to help students understand the processes of information processing, the importance of information, the basic principles of information technology services, applications, development, and the directions of formalization and automation of intellectual activities; and, thirdly, cultural - to foster an informational culture of common human values in students through the use of technological tools, thus contributing to the harmony of personality development.

In the following table the analysis of Technologies Programme, Information and Communication Technologies Programme and Natural Sciences Programme is provided.

Found CS competencies in the curricula	**Technologies programme**	**Information and communication technologies programme**	**Natural sciences programme: Biology, Chemistry, Physics, Astronomy + Geography**
Knowledge and understanding	x	x	x
Problem solving	x	x	x

Practical skills	**x**	**x**	**x**
Science communication	**x**	**x**	**x**
Learning to learn	**x**	**x**	**x**
Designing: observing the environment, formulating questions to help find out the relevant processes in the environment, coming up with and discussing ideas on what can be developed, finding the best idea.	**x**		
Designing: Anticipate the stages of implementation of the best idea, the possible difficulties in implementation and the ways to overcome them.	**x**		
Designing: Anticipate how to present the process of implementing an idea.	**x**		
Information: Determine what information will be needed to select and implement the ideas presented, write down key search terms and find it in the information sources provided.	**x**		
Information: collect, collate, add to the information needed to address the idea, justify why the information is relevant, analyze, summarize and present it in written form.	**x**		
Information: Use the information gathered to inform the presentation of the activity.	**x**		
Materials: Distinguish between materials used in the domestic environment and identify their properties.	**x**		
Materials: Given the properties of materials, select and creatively use materials and combinations of materials.	**x**		
Materials: Use materials sparingly and rationally and indicate how materials affect the environment.	**x**		
Technological processes and results: Perform technological processes for the implementation of creative ideas, anticipating advantages and possible difficulties.	**x**		
Technological processes and their results: select working tools and materials, organise	**x**		

the workplace, produce products safely, consistently, efficiently, economically and aesthetically in a safe, consistent, quality and aesthetic manner, and tidy up the workplace according to the established sequence of work operations and technological processes.			
Technological processes and their results: Indicate how the manufactured product differs from the original idea: how it fits in with tradition; what people's needs it serves What kind of tradition does it satisfy?	**x**		
Managing information on the computer: Use the computer and its devices properly for essential tasks.		**x**	
Managing information on the computer: Perform the most common actions for most computer applications		**x**	
Managing information on the computer: Correctly use computing and information technology terms and concepts.		**x**	
Computer Information Management: Handle information on a computer correctly.		**x**	
Computer Information Management: Use computer programs legally.		**x**	
Computer information management: Explain the importance of computers in everyday human activities.		**x**	
Drawing on a computer: To operate basic graphic designer tools, to create drawings independently.		**x**	
Drawing on the computer: Perform basic operations on a drawing.		**x**	
Drawing on the computer: Print out the drawing you have created.		**x**	
Creating, managing and printing text documents: Operate basic word processor tools.		**x**	
Creating, managing and printing text documents: Produce a text document on the computer.		**x**	

Creating, managing and printing text documents: Print a text document.		x	
Internet and its services: Use basic Internet terms correctly.		x	
The Internet and its services: Use basic Internet terminology when browsing the Internet		x	
The Internet and its services: Use a search engine and online directories to find information.		x	
The Internet and its services: Use an e-mail application		x	
Internet and its services: Use an Internet chat service for communication.		x	
Constructing with a computer: Operate the basic tools of a construction system.		x	
Constructing on a computer: Manage the main objects in the system, exploring their behaviour by changing the properties of each object in the options window and/or by commands.		x	
Computer assisted design: Plan and construct a simple project (drawing) on the screen using object management commands and procedures.		x	
Computer aided design: Write down the actions to be performed on an object in procedures.		x	
Computer aided construction: Use an animation editor to create simple pictures with frames.		x	
Nature research			x
Structure and function of organisms			x
Continuity and diversity of life			x
Organism and environment. Biosphere and man			x
Variations in materials			x
Knowledge and use of key materials			x

Knowledge of movement and forces			x
Knowledge of energy and physical processes			x
Knowledge of the Earth and the Universe			x

4.5.3 Italy

Although, as seen above, the educational reform has led the Italian school system to no longer be based on the concept of curricula defined at ministerial level, an analysis of preexisting decrees was conducted in order to map the typical competences of Citizen Science projects in relation to those present in the individual curricula.

Found CS competencies in the curricula	**Geography**	**Mathematics**	**Science**	**Technology**
Students orientate themselves in space and on maps of different scales according to cardinal points and geographical coordinates; they can orientate a large-scale map using fixed reference points	x			
Makes appropriate use of maps, current and old photographs, remote sensing images, digital processing, graphs, statistical data, geographic information systems to effectively communicate spatial information	x			
Recognises significant physical elements and historical, artistic and architectural features in European and world landscapes, particularly in comparison with Italian landscapes, as a natural and cultural heritage to be protected and enhanced	x			
Observes, reads and analyses nearby and distant spatial systems in space and time and assesses the effects of human actions on spatial systems at different geographical scales	x			
The pupil is confident in calculating with rational numbers, masters the various representations and estimates the size of a number and the result of operations		x		

Recognises and names the shapes of the plane and space, their representations and understands the relationships between the elements		x		
Analyses and interprets data representations to derive measures of variability and make decisions		x		
Recognises and solves problems in different contexts by evaluating information and its coherence. Explains the procedure followed, also in written form, maintaining control over both the solving process and the results		x		
Compares different procedures and produces formalisations that allow to shift from a specific problem to a class of problems		x		
Produces arguments based on acquired theoretical knowledge (e.g. can use the concepts of characterising property and definition)		x		
Supports their own convictions by giving appropriate examples and counterexamples and by using concatenations of statements; accepts to change their opinion by recognising the logical consequences of a correct argument		x		
Uses and interprets mathematical language (Cartesian plane, formulas, equations...) and understands its relationship with natural language		x		
In situations of uncertainty (everyday life, games...) they orient themselves with probability assessments		x		
Strengthened a positive attitude towards mathematics through meaningful experiences and understood how the mathematical tools learned are useful in many situations to operate in reality		x		
The pupil explores and experiments, in the laboratory and outdoors, the occurrence of the most common phenomena, imagines and verifies their			x	

causes; searches for solutions to problems, using acquired knowledge				
Develops simple schematisations and models of facts and phenomena using, where appropriate, appropriate measures and simple formalisations			**x**	
Recognises the structures and functions of the organism at macroscopic and microscopic levels, areaware of their potential and their limits			**x**	
They have an understanding of the complexity of the living system and its evolution over time; they recognise the basic needs of animals and plants in their diversity, and the ways of satisfying them in specific environmental contexts			**x**	
Pupils are aware of the role of the human community on Earth, of the finite nature of resources, as well as of the unequal access to them, and adopt ecologically responsible ways of life			**x**	
Link the development of science to the development of human history			**x**	
They have curiosity and interest in the main problems related to the use of science in the field of scientific and technological development			**x**	
Pupils recognise the main technological systems in the surrounding environment and the multiple relationships they establish with living beings and other natural elements				**x**
They know the main processes involved in the transformation of resources or the production of goods and recognise the different forms of energy involved				**x**
Can hypothesize the possible consequences of a technological decision or choice, recognising the opportunities and risks of each innovation				**x**

Know and use everyday objects, tools and machines and is able to classify them and describe their function in relation to their shape, structure and materials				x
Use appropriate material, information and organizational resources to design and produce simple products, including digital products				x
Derive from reading and analyzing texts or tables information about goods or services available on the market in order to expres evaluations with respect to different types of criteria				x
They know the properties and characteristics of the different means of communication and are able to make effective and responsible use of them in relation to their study and socialization needs				x
Can use procedural communications and technical instructions to carry out complex operational tasks in a methodical and rational manner, also collaborating and cooperating with classmates				x
Designs and produces graphical or infographic representations of the structure and functioning of tangible or intangible systems, using elements of technical drawing or other multimedia and programming languages				x

4.5.4 Greece

To identify citizen science competencies in school curricula, the curricula for physics, chemistry, computer science/IT, mathematics and geography have been reviewed in order to identify overlaps with citizen science, scientific literacy competencies and data literacy. In the following the analysis table is provided (Table 5).

Competencies in the curricula	Physics	Chemistry	Computer science	Geography	Maths	Citizen Science / Scientific Literacy	Data Literacy

Using models to illustrate (chemical) phenomena		X				X	
Extract information and data from analogy and digital media offerings, reproduce their key messages, and note the source (information processing).	X	X				X	X
Representation and interpretation	X		X			X	
Communicate and collaborate	X		X			X	
Selection of data and information, testing for relevance and reliability	X					X	
Evaluation of the hypotheses	X					X	
Interpretation of data, (trends, structure and relations)	X		X		X		X
Visualization of data with linguistic, mathematical and pictorial means of representation	X						X
Read & interpret data	X		X				X
Clean Data			X		X		X

Data Transformation			X				X
Data Presentation			X		X		X
Data Analysis	X				X		X
Explain phenomena scientifically	X	X				X	
Knowledge of science concepts	X	X				X	
Problem solving					X	X	
Scientific communication	X					X	

Table 5: Competencies in different subjects' curricula

5 Conclusions

This document has shown the theoretical background, the development and validation of the FabCitizen Pedagogical Framework and Competency Framework.
The pegagogical framework has been extended towards a guideline for schools how to implement CS in their schools. The competency model is a comprehensive model for CS as well as related areas like scientific thinking.
Based on these conceptual works, learning scenarios and materials as well as CS project are developed.

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Annex 1 Analysis Planning - Interview Guideline

The following interview guideline was used in each country. The guideline was translated to do the interviews in the local languages.

Interview design
Expert interview, semi-structured

Participants (10 per country, academic experts and school teachers / curriculum designers)

Note: Introduce the key concepts before the interviews. Parts of the presentation of the kick-off meeting can be re-used to introduce the project idea.

The interviewees should agree that the interview is recorded. The interview is anonymized on request.

1.Interviewee background data
Name/Role
Age
Level of education, year of graduation, years of teaching

2.School background data
Country, city:
Level:
Student age
school size

3.CS experience
What is your personal experience in CS projects? Can you describe a good CS project? Have you experienced CS in schools?

4.CS in curriculum
Is there a school, regional or national level curriculum for Citizen Science? How is it implemented? Is it compulsory? In which topics of the curriculum could you see CS kills to fit/to be learned?

5: Data science in the curriculum
Are there data science concepts (e.g. data acquisition, analysis, interpretation, ethics) in the curriculum? In which subjects? If not, where would they fit?

6. Support for the teachers
How are teachers supported when introducing new topics / subjects? Can they freely adapt the curriculum? Is there education, monetary support or support groups? Is the education ongoing?

7.CS skills
What are useful skills for pupils and teachers (based on https://www.citizenscience.org/wp-content/uploads/2018/11/USERS-GUIDE_linked.pdf)?
Do you see additional skills?

Competency	Pupils, which grade?	Teachers
Interest in Science & the Environment Interest in pursuing science and environmental topics, and issues.		
Self-efficacy The extent to which a learner has confidence in his or her ability to participate in (citizen) science		
Motivation Motivation to pursue science and environmental goals such as STEM careers and citizen science project activities.		
Knowledge of the nature of science; understanding of the scientific process and how science is conducted by researchers		
Data Understanding how to gather, analyze, interpret and critically discuss data Understanding how to handle data securely and ethically.		
Skills of Science Inquiry Procedural skills such as asking questions; designing studies; handling data; experimenting; argumentation; synthesis;		
Responsible Citizenship Behavior change towards		

becoming a responsible citizen (e.g. towards environmental or sustainability issues)		
Basic skills technology use; digital literacy		
Social skills Collaboration Communication Critical thinking Reflection		
Additional:		
Additional		

9. Barriers and Interventions
What are the main barriers for incorporating CS in schools = Do you have ideas how to overcome those?

Barrier	Intervention

In case that the interviewee has no idea, typical barriers can be discussed:

- Curriculum barriers: Lack of flexibility, hard to integrate
- Lack of resources (time, budget)
- Lack of skills (of teachers)
- Lack of interest in scientific projects
- Lack of active involvement
- CS is not a school issue, universities should take care of it

- Lack of interest in research / science
- Lack of benefits (e.g. certification)
- Lack of community interest

10. Needs

Do you think that CS could be a helpful practice / tool to be used in grades 5-9 in science subjects?

In which subjects would you see most potential?

What do the schools and educators need?

What would the students need?

[i] http://www.allyouneediscode.eu/documents/12411/14644/Coding+initiative+report-European+Schoolnet-October2014.pdf/66475be8-cc31-429c-a5cc-32767366c8c2

[ii] http://www.eun.org/fi/resources/detail?publicationID=661

Annex 2: Webster and Watson (2002) concept matrix for guidelines, frameworks and principles for undertaking CS projects

Table 6: Concept matrix for comparing 16 citizen science methodologies, guidelines and approaches according to Webster and Watson (2002) (own created table)

1: (Mäkipää et al., 2020), 2: (Lemmens et al., 2021), 3: (Shirk et al., 2012), 4: (Bonney, Cooper et al., 2009), 5: (European Citizen Science Association & others, 2015), 6: (Herodotou et al., 2018), 7: (Heigl et al., 2020), 8: (Johnson et al., 2014), 9: (Nowak et al., 2021), 10: (Tweddle et al., 2012), 11: (Pocock et al., 2013), 12: (Harris & Ballard, 2018), 13: (U.S. GSA, 2021), 14: (Yadav & Darlington, 2017), 15: (OEAD, 2018), 16: (OEAD, 2021)

Author / Concept	**STEP**	**GUIDELINE**	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Participants	**S**	**G**	**X**	**X**		**X**	**X**	**X**	**X**			**X**	**X**	**X**	**X**	**X**		**X**
Project is unachievable without participants		G							X				X		X			
Form a scientist / educator / evaluator /leader team	S					X						X		X				
Recruit participants	S					X						X						
Train participants & choose adequate training	S					X						X	X	X	X			X
Get to know the skill level of participants	S														X			
Involvement of citizens in scientific endeavour Contributors, collaborators, or project leaders (multiple stages)	S	G					X X	X	X			X				X X		
Volunteer participation (active / passive) Active participation of students		G										X				X		 X

Engage volunteers (as initiators of CS)		G						X	X			X			X			
Provide participants feedback and give support	S	G					X		X			X	X		X			
Create a benefit for scientists and participants		G					X		X			X						
Address different interest groups		G				X			X									
Make participants feel part of the team		G										X						
Understand participants motivation and target		G										X			X			
Participant safety		G										X	X					
Pupils can do different tasks in projects and choose them according to their interests	S	G																X
Acknowledge participants and reward volunteers	S	G					X	X				X			X			
Value users and time		G						X				X			X			
CHALLENGES			**X**								**X**						**X**	**X**
Rigid curriculum											X							
Recruiting students																	X	
Presence of the topic											X							
High workload / occupancy of teachers											X							X
Establish the projects long-term (E2)											X							
Lack of finances / sponsoring											X						X	
Time aspect (of teachers)											X						X	
Linguistic / language barriers											X							
Coordination needed with school management											X							

Timeframe for conducting CS projects											X							
(Missing) interest among the staff											X							
Motivation of teachers											X							
Location of schools											X							
Establish contact to schools / finding the “right partner”											X							
Long term duration of projects (motivating the student’s long term)											X							
Errors can lead to extra work for researchers																		X
Lack of recognition and payment of dedicated teachers																		X
PROJECT OUTCOMES	**S**	**G**			**X**	**X**	**X**		**X**			**X**			**X**			
Science Socio-ecological systems Individuals	O				X X X		X											
Observation and experiences	O											X						
Measure outcomes	S					X						X						
Science outcome (e.g. answer research question)	S						X		X			X						
Disseminate results	S					X						X			X			
Publish the results (open access)	S					X			X			X			X			
Publish the results in a comprehensible manner		G				X			X			X			X			

DATA	S	G			**X**	**X**	**X**		**X**			**X**	**X**	**X**	**X**	**X**		**X**
Understanding data needs and being aware of the data lifecycle		G													X			
Accept, edit and display data	S					X						X						
Data collection	S											X	X	X		X		X
Analyse and interpret data	S					X						X		X	X	X		
Data processing	S														X	X		
Visualize data	S											X						
Data storage	S														X			
Develop, refine and test support materials	S					X						X						
Information about CS projects		G			X													
Open science - Make data publicly available	S						X		X									
Data management plan according to European General Data Protection Regulation		G							X						X			
Protect data	S	G																X
Share data	S														X			
Measure and evaluate data quality	S											X			X			
Upload data	S													X				
SCIENTIFIC ISSUES	**S**	**G**			**X**	**X**		**X**	**X**					**X**	**X**	**X**		**X**

Identify question or issue	S				X	X			X					X				
Scientific interest		G							X									
Public interest									X									
Further investigate on youth questions		G												X				X
Scaffold the scientific inquiry process	S							X								X		
PROJECT EVALUATION	**S**	**G**			**X**		**X**					**X**		**X**	**X**			
Evaluation framework		G			X													
Evaluate scientific output, data quality, participant experience and outcomes	S						X					X						
Consider limitations and biases		G					X											
Reflect on learning / experience	S													X	X			
PROJECT SETUP	**S**	**G**					**X**	**X**	**X**			**X**	**X**	**X**	**X**	**X**		**X**
Find a suitable research question	S																	X
Get approval from the supervisors	S														X			
Introduce the project	S													X				
Learn from field guides	S													X				
Observe and sketch specimens	S													X				
Identify question	S											X	X		X			
Execute small trials	S											X						

Check whether CS is a suitable approach	S											X	X		X			
Choose the right citizen science approach	S														X			
Vary the investigation types and topics according to citizens interests		G						X										
Choose an adequate method	S								X									
Open and clear project objectives /aim		G							X			X	X		X			
Cost analysis and funding	S											X			X	X		X
Test and modify protocols	S											X	X					
Planning resources (material, spatial, personnel)	S												X		X			X
PROJECT INFRASTRUCTURE	**S**	**G**			**X**			**X**							**X**	**X**		
Development of mobile application to scaffold data collection projects	S							X								X		
Deployment (thin client /thick client / sensor data processing)	S															X		
Develop project infrastructure and manage project implementation	S				X										X	X		
COMMUNICATION		**G**						**X**	**X**			**X**	**X**		**X**			**X**
Facilitate participation through communication channels (as email notifications)		G						X	X									
Communicate key messages of learning by doing		G						X										

Communicate the doing and being part of the community		G						X										
Clear assignment of tasks		G							X									
Learn the basic terminology in crowdsourcing and citizen science	S														X			
Establish reliable communication with the contact person		G																X
Use accessible language		G										**X**						
PROJECT EXPLOITATION	S											X		X	X			
Share the results with the public (schools /city council / parents/organizations)	S											X		X				
Present to other classes	S													X				
Talk to local citizen scientists	S													X				
ETHICAL AND LEGAL ASPECTS	S	G					**X**		**X**						**X**			**X**
Project objectives must be ethically sound		G							X									
The project must follow transparent ethical principles		G							X									
Project management should consider ethical aspects as inclusion and equality		G							X									
Be sensitive to socio-cultural issues		G													X			
Consider legal and ethical issues as copyright and data sharing agreements		G					X											
Ethical approval before project start	S																	X

Assurance of the implementing, guiding project staff	S																	X
Rights of the persons depicted in pictures		G																X
Copyright and rights of use		G																X
PROJECT IMPROVEMENT	S	G													**X**			
Adapt to cycles of participation.	S	G													X			
Communicate effectively		G													X			
Solicit feedback from your participants	S														X			
Sustain your project funding	S														X			
Evaluate your participants' engagement	S														X			
Build flexibility into your project		G													X			
Know how to end your project	S														X			
SCHOOL SPECIFIC PLANNING	S	G															X	X
Contact schools before there is any concrete project planning	S																	X
Full-day project meeting (e.g. kickoff) with teachers, researchers and students	S																X	X
Take into account the different perspectives and expectations of all participants		G																X
COLLABORATION WITH SCHOOLS	S	G															X	X

Alignment of the timetable with the semester planning of the universities and the annual planning of the schools (e.g. planning in May and June, as this is when planning takes place for the coming school year takes place, consider lecture free periods, exam-intensive periods, school-autonomous days)	S																X	X
Allow time for consultation with or consent from education directors, ethics committees and parents/guardians		G																X
Keep connected to the young people to strengthen their motivation		G															X	
Being aware that students leave school after matura (time planning)		G															X	
Networked cross-thematic issues depend on the school’s location and sympathy between teachers		G															X	
Consider non-funding at the application stage to prevent frustration because of rejected proposals		G															X	
Researchers support with funding bodies	S																X	
Communication is the key for success		G																X
Open contact and communication with each other		G																X
Do not underestimate group dynamics		G																X
The level and parts of involvement of children and young people should be clear	S	G																X
Assess from which school level the requirements can realistically be fulfilled by the pupils	S	G																X

Provide local connections to strengthen the motivation of the pupils		G																X
Activation of the different potentials of pupils and teachers through the project		G																X
Let students feel like scientists and support them		G																X
Soften the hierarchy – students and teachers should see themselves as researchers		G																X
Teachers and researchers support pupils to develop their own thinking, autonomy, competency		G																X
Through selected participation methods and procedures, participation can be designed in such a way that pupils participate voluntarily		G																X
Declarations of consent for participation by parents	S																	X
Identifying scope for project work in the curricula	S																	X
Identifying the integration of inquiry-based learning into teaching	S																	X
Use the possibility of elective subjects or a free hour quota for free project work	S																	X
School budget planning	S																	X
Establish projects long-term (contact point for schools, cooperation)	S																	X