Education in Technology for Sustainable Development Applied to School Gardens

Sara Blanc, José V. Benlloch-Dualde, Laura Grindei, Ana C. Torres, Angélica Monteiro

***Abstract*—**This paper presents a study that leads an experience by introducing digital learning applied to a case study focused on primary and secondary school garden-based education. The approach represents an example for interaction among different education and research agents at different countries and levels, such as universities, public and private researches and schools, to get involved in the implementation of education for sustainable development that will make students become more sensible to natural environment, more responsible for their consumption, more aware about waste reduction and recycling, more conscious of the sustainable use of natural resources and, at the same time, more 'digitally competent'. The experience was designed attending to the European digital education context and OECD (Organization for Economic Co-operation and Development) directives in transversal skills education. The paper presents the methodology carried out in the study as well as outcomes obtained from the experience.

***Keywords*—**School gardens, primary education, secondary education, science technology and innovation in education, digital learning, sustainable development goals, university, knowledge transference.

I. Introduction

TECHNOLOGY evolves quickly and change our world. It is not only the way of finding information or chatting among our contacts, but also the way to connect with the reality and how the deep knowledge in technology empowers people to transform the future being part of the change, not just looking like mere spectators. It must be the new consideration about education in Science, Technology, and Innovation (STI).

STI is transversal to any transformational change, in industry, in agriculture, in social development, among others. New skills and expertise are required to promote an overall sectorial adaptation leaded by technology. For example, expert systems, artificial intelligence, or machine learning are just some of the trend topics which the Organisation for Economic Co-operation and Development (OECD) touches on the STI Outlook 2018. The OECD is aware of the need to bring technology and society closer also to bridge the existing gaps that slowdown the achievement of the Sustainable Development Goals (SDGs) [1].

Some megatrends such as the efficient use of natural resources and energy or the environment care can be favored by digitalization. However, digital and technological skills are complex and cross with a personal growth in cognitive learning as well as socio-emotional and behavioral learning. Thus, learning should start at the school. Moreover, because of the complexity and quick evolution of the mentioned trend topics, specialized actors such as universities or research centers have a duty to contribute to the transformational change. The transference of knowledge from higher education institutions and universities to schools should focus on specific problems that raise students' awareness as well as empower them to find innovative solutions to problems by themselves.

Enhancing the educational process through innovative pedagogies and digital skills, strengthening the link between education and research, and promoting the knowledge transfer between education agents and society are all topics that represent important challenges.

An example is the project "School Gardens for Future Citizens" (eSGarden) funded by the European Commission [2] (2018-2021). Such initiatives from EU favor the collaboration among agents of different education levels and researchers from public and private sectors.

This paper presents the experience of eSGarden that connects technology with education through the trend topic of human sustainable development. As case study, the project focused on school gardens as dynamic spaces for learning about biodiversity, discussing about human actions and observing the nature, while children and young people plan and manage the garden, cultivate the crops, carry out experiments and actively communicate their work outcomes to the local community.

Fig. 1 Connecting school gardens and technology: Learning principles

School gardens are a rich and effective case study for the transmission of values on sustainability and awareness of

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environment caring and protection, linked with the SDGs. In addition, it is a case study that facilitates the introduction of the technology gradually, making classes more interactive and interesting for the young generation. Fig. 1 represents the principles applied to this study: Sustainability, Progress, Empowerment and Social Values.

This study differs from others similar around school gardens because its focus is biased to use ecologic gardens only as a case study to bring innovative practices in a digital area up. The project connects both virtual and real worlds with the goal of motivating students learning. It started with the creation of school gardens, which are inclusive spaces from real world that ensure an appropriate environment for applying learning-by-doing methodologies. By working in teams, working on projects and using digital tools and resources, students improve their skills. Moreover, the experience benefited teachers as well as students. In fact, the methodology carried out in this study achieved the following objectives:

1) Transform school gardens into circular knowledge breaking frontiers in a global expansion throughout a diverse community. It makes young students grow sensible to natural environment, responsible for their consumption, aware about waste reduction and recycling and the sustainable use of natural resources.
2) Develop ICT tools and resources to promote students' interaction with technology in schools through digital activities. This objective addresses the improvement of students' STI capabilities by working on real case studies and "out of the box" experiences.
3) Develop knowledge and help teachers and staff to make school gardens a sustainable tool.

The paper is structured as follows. Section II is devoted to a key literature review. Section III describes the methodology of the study. Section IV introduces the main outcomes of the experience and Section V concludes the paper.

II. Key Literature

The objective of this study is to connect school curriculum with school garden and technology and digitalization. As a result, schools' educational programmes include hands-on activities leading to a learning-by-doing model. This approach trains students in environmental education and prepares them to transform issues into solutions. Therefore, the challenge is to carry out a full procedure that, under a general framework, allows every school to design an ad-hoc programme.

The framework is established based on competences. Competences are the foundation of learning programmes and they use to be specifically defined accordingly with well-defined frameworks.

Based on a review of literature, different acknowledged international frameworks for what is commonly referred to as 21st century competences (or skills) were found. Although other terminologies such as life skills, critical skills, soft skills or even digital skills are also utilized, the terms 21st century competences and skills are broadly accepted [3]-[12] for its use in international educational agendas and frameworks as the ones of the European Commission [13], [14] and OECD [15].

The revised European Commission reference tool of key competences for lifelong learning addresses the definition of competences as a combination of skills with knowledge and attitudes, considering skills as abilities that may be embedded throughout several key competences [16]. This recent and influential framework highlights key competences to be developed not only in formal schooling, but also on diverse learning environments throughout life, specifically: Literacy competence; Multilingual competence; Mathematical competence and competence in Science, Technology and Engineering – referred to as STEM in other frameworks -; Digital competence; Personal, Social and Learning-to-Learn competence; Citizenship competence; Entrepreneurship competence; Cultural Awareness and Expression competence. It also recognizes the transversal character of certain skills, such as creativity and critical thinking, which are referred to as being important for several of the framework competences, namely Literacy, Digital competence, Citizenship and Entrepreneurship. More social skills such as empathy and respect for others and diversity are appreciated for the development and exercise of Social competence, Citizenship, Cultural Awareness and Expression, Multilingual and Intercultural competence.

Otherwise, the OECD, in its quite recent Learning Compass 2030, uses this visual metaphor to illustrate a view of competencies as complex learning dimensions that include knowledge, skills, attitudes and values [15]. This framework - a product of very broad collaboration of international educational actors from all sectors and countries - goes far beyond, separating core foundations from transformative competencies that students should acquire throughout their learning experiences, in a 2030 horizon. Much as in the EU framework, social and emotional skills, such as the already mentioned empathy and respect, are viewed as essential in improving both diversity and as personal competences potentiator. However, they are particularly highlighted as being key constructs, along with creativity, problem solving, resilience, tolerance for complexity and ambiguity, and a sense of responsibility, in the transformative competence of "reconciling tensions and dilemma". Moreover, skills such as critical thinking, creativity and collaborating with others are regarded as essential in developing the students' ability to "create new value", another designated transformative competence advanced on this framework. A final transformative competence proposed on this framework is "taking responsibility" which implies developing a strong ethics of action and commends student development of attitudes and values such as compassion, tolerance, respect for others, empathy and considering others' perspectives, as well as critical thinking, self-awareness, self-regulation, and reflective thinking.

Considering the mentioned frameworks, this study worked on a set of personal and transversal *skills* by means of project-based and problem-based learning activities:

- Mutual respect and collaboration
- Empathy and appreciation of others
- Active listening

- Acceptance of difference and diversity
- Tolerance, solidarity, and support
- Active and democratic participation
- Creativity and critical thinking
- Team working and problem solving
- Communication effectiveness
- Foreign languages
- Cultural awareness and expression
- Plural identity

Moreover, and focused on Sustainable Development and is connection with school gardens, the main *objectives* of the proposed learning activities were to learn about:

- Efficient use of natural resources
- Waste reduction and recycling
- Sustainable production and sustainable consumption
- Nutrition and health

Since the first European Recommendation on key competences for lifelong learning [13], digital competence has been acknowledged as one of the 8 key competences by the European Union. According to the Council of the EU, in 2018, [14], digital competence is defined as "the confident, critical and responsible use of and engagement with digital technologies for learning, work, and participation in society".

Started as a project in 2010, the Joint Research Centre (JRC), the European Commission's science and knowledge service, developed the European framework for digital competence, addressed to both citizens and learners. Since the earliest version, referred to as DigComp 1.0 [17], it has become one of the reference frameworks to understand what it means to be digitally competent at European level. DigComp 2.0 [18] updated the terminology and conceptual model, but also introduced implementation examples at different levels.

The current version, known as DigComp 2.1 [19] is structured in five dimensions. Dimension 1 divides digital competence in five key areas: i) Information and data literacy; ii) Communication and collaboration; iii) Digital content creation; iv) Safety; and v) Problem solving. Dimension 2 defines each of the 21 competences through learning outcomes. In dimension 3, these learning outcomes are mapped across eight different proficiency levels, ranging from beginner to highly specialized. To complete the framework, dimension 4 give details of knowledge, skills, and attitudes applicable to each competence. Finally, dimension 5 offers examples of use on the applicability of the competence to different purposes.

The necessity to prepare digitally competent students creates new demands on educators who must not only be digitally competent themselves, but also need a set of particular competences to enhance their teaching and learning. For this purpose, a specific competence framework for educators, the European Framework for the Digital Competence of Educators [20] has been created.

Attending to this framework, in eSGarden, learning activities were designed for an active learners' working in collaborative skills and digital skills in the DigCom framework.

III. Methodology

School gardens work can be integrated into many activities carried out in curricular subjects. Moreover, activities would additionally work many STI competences. In such a way, it is needed a scenario potentially useful to propose different types of learning activities highlighting the following learning challenges (Fig. 2):

A. To work on transforming students' sustainable cognitive patterns. These activities can be carried out in classroom and are focused on expanding learning beyond the boundaries of the school garden itself.
B. To work on appreciating environmental care, ecosystems conservation, waste reduction and recycling, among others. These activities, recognized as out-of-the-box activities, are mainly carried out in the real garden, and link with curriculum content.
C. To work on developing empowerment competences to use technology in an active live pro sustainable consumption and production.

Fig. 2 represents how learning activities can be sequentially scheduled to connect the three challenges with technology. Schools started using the technology as a resource in classroom activities. In a project-based or problem-based learning approach, different subjects contain units which could be refocused to environmental and biodiversity aspects.

It is important to point out that it is assumed a scenario where schools start as beginners in both gardening and technological development.

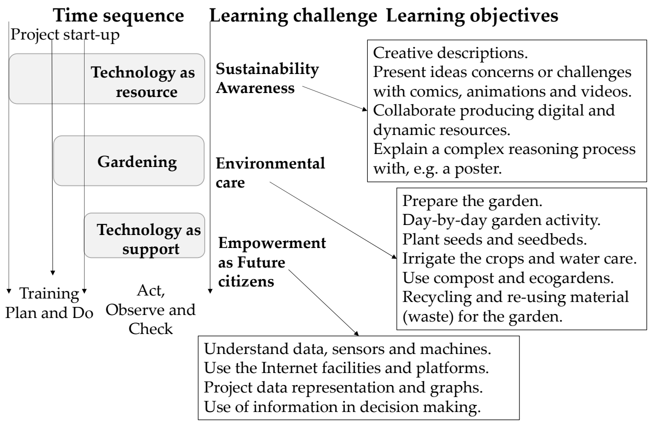

Fig. 2 The Learning Challenges Chronogram

A. Technology as a Resource

To prepare the school, the community who leads the experience should start even before gardening tasks. Many different learning activities that incorporate technology are affordable by using available web resources, tools, and cloud platforms such as online evaluation tools, graphical tools, interactive video creation, screen-casting or authoring tools.

Activities such as collaborative production of learning resources can be defined as a tasks chain which starts by acquiring new information or knowledge, classify it, analyse it for a deep understanding and finally, manage information itself to make it useful to others as well as manage digital tools to host and present it.

An example of learning activity is the collaborative production of multimedia resources about environmental issues, such as comics, blogs or picture albums, storytelling, etc. It is a familiar task for many students who have experimented throughout social network applications. However, a step forward in education is to work in the difficult task of defining the means, resources, objectives, and contents for our particular ad-hoc application.

EU DigComp competence level for teachers is assumed between advanced to highly specialized. Most relevant are presented in Table I. Tasks should be well defined by teachers while students advance in autonomy between foundations, or with guidance to pre-intermediate, or on their own.

In relation to the interaction among the different education and research agents, teachers are the main receiver of cooperation activities which are focused on training and recommending new Information and Communication Technology (ICT) tools and platforms. Collaboration leads to share ideas and propose collaborative activities among schools. Thus, output materials should include tutorials, LMS-platform-based courses, multimedia resources, etc. [22]

TABLE I
EU DIGCOMP COMPETENCES IN COLLABORATIVE PRODUCTION OF LEARNING RESOURCES ABOUT ENVIRONMENT

Competence area	Competence
Information and data literacy	Browsing, searching, and filtering data, information and digital content
	Evaluating data, information, and digital content
	Managing information and digital content
Communication and collaboration	Interacting through digital technologies
	Collaborating through digital technologies
	Netiquette
Digital content creation	Developing digital contents
	Copyright and licences
Problem solving	Solving digital problems
	Creatively using digital technologies
	Identify digital competence gaps

B. Gardening

Gardening tasks and activities will flow in parallel with curricular activity but taking also into account seasons, weather, and other environmental conditions. Preparing the garden starts with initial tasks on the soil, raising seeds in seedbeds and nurseries, and making decisions about irrigation or compost usage.

Although being a necessary step in the overall project frame, activity can be planned as both infrastructural and educational.

Tackled competences according to EU DigComp framework are shown in Table II. Digital competence levels for both teachers and students are assumed between intermediate and advanced. Learning activity tasks are based on information retrieval about gardening. In such a way, project cooperation is aimed to produce reliable and useful information for gardens planning and caring, recycling and agro-instrumentation.

In relation to the interaction among the different education and research agents, school community is the receiver of cooperation activities which are focused on a start-up training in gardening and garden actions. Collaboration is also considered among schools by sharing experiences and good practices [22].

Output materials should include videos and electronic books, recommendations and direct support.

TABLE II
EU DIGCOMP COMPETENCES IN THE PREPARATION AND CARING OF THE SCHOOL GARDEN

Competence area	Competence
Information and data literacy	Browsing, searching, and filtering data, information and digital content
	Evaluating data, information, and digital content

C. Technology as Support

School gardens promote many positive experiences to face environmental issues. A way to connect environmental care and STI is by developing a gardening system to observe the garden and help in the decision-making process about water consumption for irrigation, compost or harvesting, among others. Students learn by caring and respecting the environment through activities in contact with the garden but also out of the garden, transversal to any subject, including the development of tools to observe the garden with "digital eyes", as well as managing information, collaborate through digital tools, etc.

To bring digital competences and innovation closer to the school garden, we chose the Internet of Things (IoT) approach [21], complex enough but manageable.

Learning-by-doing favors deep learning significantly if students work in a real project. However, real computer-based or technological problems use to be complex to start with. They imply many new knowledge and capacities which should be acquired step by step.

Schools are absorbing IoT technologies little by little with the adoption of different commercially available systems. While it helps collaborative learning, other advantages underlie with the introduction of motivating experiences and a cutting-edge culture in the school. However, education cannot be articulated only around students' maturity as digital users which implies basic and intermediate levels of autonomy. Being digital users is a requirement for them who should learn about the efficient and safe use of technology either at school, integrated in the curricula, or outside even with the risks involved in a non-parental-or-teacher driven guide.

A step forward for schools is to train their students as solution developers which means an advanced autonomy level. For instance, technology helps to the improvement of productive processes in real agriculture. Thus, the same concept is adapted to schools to train students in skills and concepts which will empower them to fulfil their responsibility with the environment and society.

The introduction of activities and tasks linked with technology as support in gardening requires advanced digital skills as well as a garden to be observed. Therefore, learning activities around the last item in Fig. 2 starts later in the project.

To understand teachers training we divide IoT learning into three knowledge domains, from sensors or things to user intervention.

1) The Things Knowledge Domain

It brings students closer to the physical layer or hardware. It is the contact with devices which connect physical world with Internet. Applied to gardening, "things" are sensors and students will learn about programming languages, devices, and data understanding. The Things Knowledge relates to advanced and highly specialized coding tasks.

2) The Information Knowledge Domain

It represents the connection with the digital world. Machine to machine communication, cloud data storage and retrieval, information management or processing are main aspects related to Information Knowledge. The complexity level varies from intermediate, by adopting commercial "connect-and-play" platforms, to high specialized, by developing ad-hoc solutions.

An example in the use of both Things & Information knowledge for learning activities is the management of irrigation cycles and water consumption. Although it is focused on the technologic development, it also includes actions linked with the previous modules: Technology as a resource and Gardening. In this case, addressed competences according to EU DigComp are shown in Table III. Competence level for teacher is assumed high, while students move from intermediate to advanced. Activities introduce IoT systems, from sensors to ad-hoc APP developed and Cloud-based applications to observe soil humidity and environmental parameters. Observed information is analysed to reasoning about water consumption, and sustainable consumption.

In relation to the interaction of the partnership, specialized teachers with informatics medium-level skills are the receivers of cooperation activities which are focused on advanced training in tool kits such as Arduino or Raspberry Pi commercial embedded devices, public Data Bases, communication protocols, Block based-programming, such as Scratch, and app development.

TABLE III
EU DIGCOMP COMPETENCES IN WORKING WITH SENSORS, TOOL KITS AND IOT CLOUDS

Competence area	Competence
Information and data literacy	Evaluating data, information, and digital content
	Managing information and digital content
Communication and collaboration	Interacting through digital technologies
	Sharing information and content through digital technologies
	Collaborating through digital technologies
Digital content creation	Developing digital contents
	Integrating and re-elaborating digital contents
	Programming
Problem solving	Solving digital problems
	Identifying needs and technological responses
	Creatively using digital technologies
	Identify digital competence gaps

3) The User Knowledge Domain

Probably it is the most relevant from the point of view of sustainability. User Knowledge works in the cognitive domain looking for solutions to real problems, with special attention on the SDGs learning objectives, such as sustainable use of natural resources in agriculture.

Machine-Human interaction is a powerful duple when the human can decide about the objective for such interaction. In other words, User Knowledge makes the technology useful. In such a way, digital expertise increases from the use of apps, websites, the Internet search engines, and so on, to a proficiency level with the development of apps or new digital contents.

In relation to the interaction among the different education and research agents, the outputs are final tools. For example, attending to current tendencies, an app is a suitable output to observe data received by the sensors developed in the Things Domain and combined with the use of easily accessible databases. Some useful examples are Firebase by Google, The Things Network, or Arduino Cloud [22]. Thus, in the EU DigComp competences shown in Table IV, competence level for teachers and students is assumed intermediate, since it is reduced to the use of a simple app, marketplace and administration.

TABLE IV
EU DIGCOMP COMPETENCES IN THE PREPARATION AND CARING OF THE SCHOOL GARDEN

Competence area	Competence
Communication and collaboration	Interacting through digital technologies

IV. OUTCOMES OF THE STUDY

In an interactive context among different education and research agents we would difference between project activities and learning activities for students. Project activities are due to favor PDAOC core methodology: Plan, Do, Act, Observe and Check. These activities combine cooperation and collaboration between different actors. For example, to train gardening or new technology skills, cooperation is essential to support edge-cutting training. However, those activities that are proper of schools should not be influenced by external actors. Such is the case of route plans and learning activities definition. Schools are the owners for making decisions about these items. They are the most experienced ones and who better could find out strengths and weaknesses to promote the change and achievement.

Following the route plan definition, feedback would improve activities scope, especially for those activities which could be projected as collaboration between schools.

This study involved four schools in four different countries in Europe with participation of 14 students' cohorts. Cohorts do not embrace the whole school but those target groups which would better benefit from learning activities. Cohort size was between 20 and 30 students each. Fig. 3 shows students' ages.

Cohorts present important strengths such as curiosity, motivation to work in projects, kindness, empathy of others or motivation in using digital tools. However, the weaknesses observed in this cohorts reveal some lacks that would be enhanced. Fig. 4 shows the number of cohorts which presented some weakness in some of the transversal skills above listed.

Fig. 4 shows that team working and problems solving, as well as mutual respect and collaboration are relevant aspects to improve. Thus, most of learning activities are designed to work in teams focused on collaboration.

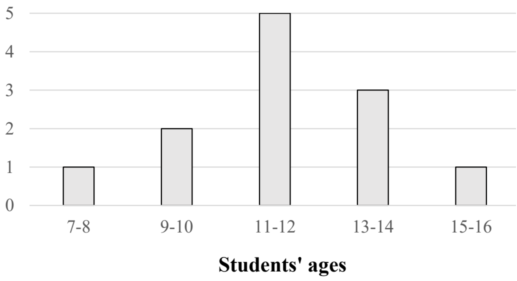

Fig. 3 Ages of the students participating in the study

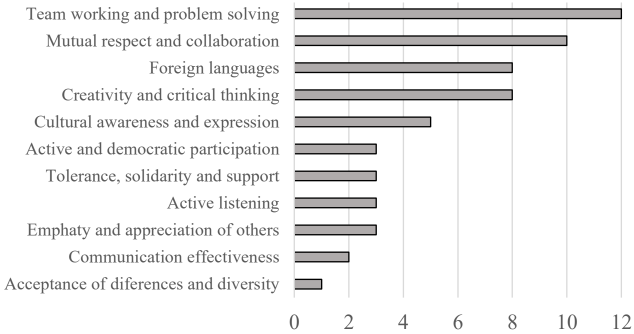

Fig. 4 Number of cohorts that explicitly worked on some skill

On the other hand, the challenge was to design activities that combined the work on personal skills, digital skills and the sustainability objectives, all above described. Each school designed learning activities that enrolled different subjects. As a result, we can describe the main elements of these activities according to the implemented objective:

Nutrition and health (subjects: Languages, Science and Technology): Through the subjects related to foreign languages students discovered new vegetables and crops for the garden. Together with colleagues from other schools, and via online meetings, they proposed a cookbook to use at home with our family. They spoke with experts via videoconference and discovered local products, the nutrition pyramid, what the carbon footprint means and how to reduce it.

They talked about the Mediterranean diet and the vitamins of the most named fruits and vegetables in this diet, searching for information on the Internet and using simple digital tools to create posters, sketches, videos, and a simple eBook.

Interaction with another school allowed them to get to know other cultures and typical recipes of their colleagues, discuss nutritional aspects and learn words in another language.

Waste reduction and recycling (subjects: Science, Biology, Chemistry and Arts): The aim of these activities was to encourage students to reduce the amount of their waste, to prevent pollution, to be creative and to think like designers.

The activity evolved in two lines. On the one hand, it promoted the use of recyclable materials to create useful objects, whether for use in the garden, decorative or for use at home. On the other hand, it explored concepts related to chemistry on basic elements such as carbon and nitrogen. Students learned the decomposition of materials and apply this knowledge to make a compost box and design a plan for the entire school to participate in making compost for garden.

In technology, they took advantage of gamification and interactive videos to create simple content to prepare campaigns such as "zero food waste lunch day" or the collection of leaves and wood for our compost.

Sustainable production and sustainable consumption (subjects: Mathematics, Science and Geography): These activities consisted of creating a two-dimensional and/or three-dimensional design project, with the intention of creating a vegetable garden and garden in a physical space existing in the outer space of a school.

Through mathematics they though like architects of the garden. Water is the common thread of the activities. They must be responsible consumers both individually and at school and in the garden.

Moreover, they practiced mathematical concepts with digital 3D CAD design tools and apps for geo-positioning and visualization of the earth. If possible, they introduced 3D printing to make small objects to scale.

Finally, they learned science with experiments related to soil and water and explored the environment to discover the biodiversity in it and become aware of its care.

Efficient use of natural resources (subjects: Technology, Economies and Geography): Technology is very important to observe and use observation to make decisions.

Students learned about macroeconomics and agriculture with a global vision. They talked about the changes in agriculture throughout history, for example, in crops, extensions, economy and technological development.

Inanimate environmental factors are the common thread of the activities. So, they learned about simple sensors, but they also build complex ones like the pluviometer with a 3D printer. They acted as true engineers. They designed and deployed a weather station, using humidity and temperature sensors or making a scarecrow for their school garden. They used technology to be the promoters of environmental awareness at school with a blog and a channel on social networks.

V. CONCLUSIONS

Global issues require changes in our lifestyles and a transformation of our way of thinking and action. In order to achieve this change, new skills, values and attitudes that eventually lead to a sustainable society are necessary. Education institutions should be involved in these changes by introducing pedagogical methods that empower students while including sustainability principles in their management organisations.

Education for Sustainable Development (ESD) represents an interesting approach to form future responsible adults [2]. This study represents an initiative to take real steps in introducing the digital competence in a ESD trend topic project-based learning approach.

The study was developed with the collaboration of universities, research centres and four schools in Europe.

The alliance of educational actors would benefit from a fast and motivated knowledge transference in different fields. The objective of such an alliance is to share experiences, good practices, keep up to date with knowledge, and work on adapting school's curricula to be more environmentally aware, and using technology as a vehicle. Based on applying new trends and technologies in education, knowledge transfer also implies innovation and research. All people involved in the project develop new capabilities through applied research specially teachers and students enrolled in the project.

The study presented in this paper describes an experience that combines school gardens and gardening with technology setting the connection between learning activities, skills and competences. Technology is presented as a vehicle-tool in our project of building and caring a school garden (see Fig. 2). First, students design and manage the garden using easy to use digital tools. Second, the garden becomes a resource to observe and gather data and information. Finally, students advance forward learning complex digital concepts and skills focused on a trend topic as IoT. Moreover, the learning activities go beyond the garden, involving different subjects, and working on various aspects related to ESD.

On the one hand, the alliance allowed the improvement of teachers' skills and knowledge, and generated new materials and resources. On the other hand, the teachers were able to design new learning activities, ad-hoc according to the specific needs of the student cohorts, introducing digitalization as a support for the learning objectives and sustainable development as the common thread of the project-based and problem-based methodologies.

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