

Article

The Smart Classroom as a Means to the Development of ESD Methodologies

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Received: 27 February 2020; Accepted: 6 April 2020; Published: 9 April 2020



Abstract: Educational institutions are envisioned as principal agents for addressing the current sustainability challenge that society is facing. Education for Sustainable Development (ESD) is transformational and concerns learning content and outcomes, pedagogy and the learning environment in itself. ESD entails rethinking the learning environment (physical and virtual) in line with sustainable development, which implies classrooms' transformation towards learner engagement, formative assessments and active methodologies. This paper responds to this need through exploring the relationship between Smart Classrooms and four widely used ESD methodologies (project or problem-based learning, case study, simulation and cooperative inquiry), identifying how the dimensions and categories of the characteristics of Smart Classrooms can contribute and lead to the implementation of ESD methodologies in real teaching practice in an effective way. The method used in this study consisted of a literature review of both theoretical frameworks separately, ESD and Smart Classrooms, and a subsequent expert analysis to identify the interrelation between both. The Smart Classroom shows a high level of adequacy for using problem and project-based learning, case study and cooperative inquiry methods because of its characteristics in terms of technology developments, environmental conditions and processes. Simulation is the ESD methodology with the lowest level of adequacy in a Smart Classroom, because it is primarily held online rather than through face-to-face teaching. Smart Education facilitates the putting in practice of ESD processes as it enables the creation of intelligent, sustainable, resource-efficient, personalised and adaptive learning environments. Further empirical research is needed to explore the influence that the Smart Classroom has in enabling ESD processes and practices, and to identify students' and teachers' needs at different education levels. Additionally, teacher training programmes focused on the correct use of Smart Classrooms and on the digital competence of teachers are critical to its successful implementation.

Keywords: smart classroom; smart education; education for sustainable development; teaching and learning methods; competencies; sustainability; learning environments

1. Introduction

The previous two decades have seen a thriving acknowledgment and political understanding of education as a key promoter of a more environmentally aware, social and equitable society [1,2]. This is evidenced by several national and worldwide political advancements and agreements; for example, the United Nations declared in 2005 the Decade of Education for Sustainable Development (abbr. UNDESD, 2005–2014), which was led and coordinated by UNESCO; in 2011 the United Nations Economic Commission for Europe (UNECE) also approved its own Strategy in Education for Sustainable Development (ESD); and in 2015, world political leaders approved the 2030 Agenda for Sustainable Development, which includes a set of 17 Sustainable Development Goals (SDGs), with specific targets to be achieved by 2030 [3].

The proclamation of the UNDESD in 2005 catalysed the integration of the ESD principles into all levels of education [1]. Educational institutions are envisioned as principal agents for tackling the sustainable development goal that humanity is confronting, where interdisciplinarity, transdisciplinarity and innovative action are essential [2,4]. The educational programme, teaching methods, the structure and functioning of infrastructures and resources, and the existing values and beliefs within the organization are intrinsic elements of education; this implies that integrating ESD needs a holistic change affecting the whole educational institution, and concerns the content, students' results, teaching methods and the organisation of the classroom, instead of the adding of supplementary topics or themes on sustainability into existing subjects and educational programmes [5,6].

Therefore, ESD involves reconsidering the physical and virtual learning space in line with sustainable development, which implies classrooms' transformation towards learner engagement, formative assessments and active methodologies. In this context, Smart Education gains force as a means to put in practice ESD processes as it enables the creation of intelligent, personalised and adaptive learning environments [7]. Smart Education is critical to the Smart Learning Environments because it reduces students' cognitive load, and enables sense making and ontological construction amongst students [7].

In relation to Smart Learning Environments, there is an increasing interest to boost Smart Classrooms and their potentialities. Smart Classrooms are educative spaces endowed with technology in different senses, from the incorporation of digital devices and learning software to the inclusion of sensor networks that help with tracking classroom processes, gathering data and offering insights to help decision making for better and faster learning, to provide more convenient teaching and learning conditions for educators and students. Thus, it seems clear that technology must be adapted to pedagogical aspects, giving response to educational needs rather than being included as a merely innovative but unconnected solution. Adapting environmental conditions such as lighting, acoustics and air quality control are also an inner part of the Smart Classroom core definition, as these factors have a direct impact on learners, in terms of comfort and well-being and, as a consequence, on their performance.

This paper responds to the need to rethink learning environments in order to facilitate the integration of ESD methodologies at any educational level (Primary, Secondary and Higher Education), through determining the relationship between Smart Classrooms and four widely used ESD methodologies (project or problem-based learning; case study; simulation and cooperative inquiry), identifying how the dimensions and categories of characteristics of Smart Classrooms can contribute and lead to the implementation of ESD methodologies in real teaching practice in an effective way. The proposed reference characterisation of Smart Learning Environments and Smart Classrooms developed by Palau and Mogas was used to conduct the analysis (see Section 2). This work grouped the characteristics of Smart Classrooms into a set of categories included in three main dimensions: technology, environmental conditions and processes. Therefore, an expert analysis was conducted to explore the relationship between Smart Classrooms and ESD methodologies. In this analysis four ESD teaching and learning methods were selected and examined for each of the eight categories identified in the Smart Classroom to establish its the level or degree of adequacy for each method. The relationships and the potentialities offered by Smart Classrooms drawn in this study can be suitable and transferable to any education level: from pupils of first to eighth grade, to bachelor and master students.

In the second section of this paper, the ESD rationale and teaching and learning approaches are outlined. We focus on four methodologies that have been widely used and recognised in the literature as to lead to the development of sustainability competencies: project or problem-based learning, case study, simulation and cooperative inquiry. In the third section, Smart Learning Environments and Smart Classrooms are conceptualised according to their three main dimensions: technology, environmental factors and the processes developed. In the fourth section, the method and processes followed to conduct this study and the expert analysis are outlined. In the fifth section, the contribution of the Smart Classroom to ESD is explored, establishing the relationship between the dimensions and

characteristics of both. Suggestions on how Smart Classroom dimensions contribute to the performance and development of ESD methodologies are also provided. The final section of this work is devoted to presenting the main conclusions and six key implications for action to create learning environments that assist the progress of ESD.

1.1. Education for Sustainable Development

1.1.1. What Is Education for Sustainable Development (ESD)?

The relevance of education in creating sustainable communities based on social justice, equity and sustainability has been acknowledged nationally and internationally, by agencies like the United Nations, UNESCO and UNECE, which have approved numerous schemes and action plans over the last two decades [2,8,9]. The declaration of the UNDESD (2005–2014), led by UNESCO, acted as a promoter of the integration of sustainability within different educational contexts and levels to address, from an educational standpoint, the global challenges that current society is confronted with. Additionally, the Sustainable Development Goals (SDGs) agreed by the international community in the United Nations recognise the importance of education, by determining a specific SDG on Quality Education (SDG 4) and by defining a set of targets and indicators that should to be achieved by 2030 [3]. Target 4.7 of SDG 4 specifically focuses on ESD and the knowledge of and skills in sustainability that have to be developed amongst all type of learners to create global citizens that can actively contribute to a more sustainable society, including gender equality, sustainable consumption, human rights, cultural diversity and peace and democracy [9].

ESD has to be understood as a transformative learning process towards sustainability, which is based on innovative teaching and learning practices, a diversity of methods, problem-based learning, critical reflection, the appraisal and clarification of self-values and existing conceptions, and context- and action-based learning [10,11]. ESD embraces, as its core, the capacity to think in alternative futures or scenarios, critical and creative thinking, collaboration, participatory decision-making processes, partnerships, active and participatory learning, interdisciplinarity and systems thinking [12].

Emerging research has focused on defining the conceptual or theoretical frameworks of sustainability competencies and learning outcomes that need to be nurtured in students through formal education programmes in order to promote sustainability literate citizens [13–16]. Different studies have focused on defining and conceptualising sustainability competencies' frameworks. For example, Rieckmann [17] led a Delphi study in which ESD experts contributed to identify core sustainability competencies, such as systems thinking, critical and anticipatory thinking. Moreover, Lozano, Merrill, Sammalisto, et al. [18], in a recently conducted literature review, have come up with an integrative framework composed of twelve sustainability competencies, namely: systems thinking; interdisciplinarity; anticipatory competence; values and ethics; critical thinking and appraisal; interpersonal competence; intrapersonal competence, including empathy; communication skills; strategic thinking and planning; personal engagement; evaluation skills; and dealing with uncertainty and resilience. Wiek, Withycombe and Redman [16] also created an integrative framework on sustainability research competencies. Through the reviewing of existing research and frameworks, they identified five key sustainability competencies, which correspond to “systems-thinking competence, anticipatory competence, normative competence, strategic competence, and interpersonal competence” [16] (p. 205).

Further research in ESD has also explored and nailed down sustainability competencies in different professional contexts, making the effort to contextualise these competencies for different subject areas and professions such as engineering [19] and education [13,20]. Likewise, international organisations like UNESCO [1,9], UNECE [21] and accreditation agencies [22] have made plausible the significance of establishing subject-specific frameworks on sustainability competencies and learning outcomes. In a recent UNESCO publication, a set of learning purposes for each of the 17 Sustainable Development Goals of the 2030 Agenda for Sustainable Development are outlined [9].

In terms of the processes of evaluating sustainability competencies, the importance of context-based assessment tools is emphasised, including a diverse range of instruments, from summative to formative assessments, comprising self- and peer-evaluation. Questionnaires are most widely used, while emerging literature presents reflective diaries, conceptual maps, interviews, rubrics and vignette questioning instruments as suitable tools [13,18,23]. However, it should be noted that this is a rather new and evolving research area. To date, little evidence exists regarding the impact that courses focused on developing these sustainability competencies have on students' learning, and their change in perspectives and sustainability literacy [18].

Innovative and transformative learning approaches towards sustainability need to be conducted and empirically researched, in order to provide evidence regarding the influence that these have on leading sustainability competencies' development [23,24]. This paper establishes the interrelation between a set of selected ESD methodologies and smart learning environments, with the aim of exploring how smart learning environments and the Smart Classroom can contribute to putting ESD into practice in an effective way.

1.2. ESD Methodologies

In this paper, we focus on four student-centred methodologies that have been widely used and recognised in the literature to lead to the development of sustainability competencies: (1) project or problem-based learning, (2) case study, (3) simulation and (4) cooperative inquiry.

A considerable amount of the literature on sustainability has focused on pedagogical aspects related to sustainability [18,25]. ESD includes the content and the instruction approach; therefore, it is about leading-edge pedagogies [26]. Integrating the principles of sustainability in education requires a methodological innovation towards inquiry-based learning, student-centred processes, and active and experiential learning approaches that provide opportunities to learn from, and in, real practice [5]. It encompasses a holistic view, interdisciplinarity and working with different stakeholders, where students can acquire new knowledge and skills while making a significant contribution to the sustainability of their local community. Therefore, educators have to become role models and co-learners, promote learning through experience and system thinking amongst their students [18].

The existing body of knowledge suggests a number of approaches to teaching in line with sustainability. For example, Tejedor and colleagues [27] conducted a review of five didactic strategies relevant for introducing sustainability competencies amongst university students: service learning, problem-based learning, project-oriented learning, simulation games and case studies. The authors, through an expert analysis of the didactic strategies, identified how these should be implemented in practice, considering three stages of application: the planning stage, the application stage and the student evaluation stage. Moreover, Transformative Learning for Sustainability is an extensively accepted ESD pedagogy within the ESD academic community, which is based on the integration of three spheres of learning: cognitive functions, emotions and physical movement [15,28,29]. Transformative Learning for Sustainability promotes the questioning of existing understandings and viewpoints, values and assumptions that are conditioned by our culture and previous experiences [29]. In this context, critical appraisal, collaboration and active participation are critical, as these allow new actions and practices, and decision-making processes based on more democratic and participatory bases [30].

Offering realistic and context-based learning situations, through using student-centred approaches such as project- or problem-based learning and experiential learning, is fundamental for students in order to mobilise critical thinking and reflection, autonomous learning, active engagement with the community and research skills [28,31]. Project- or problem-based learning is a didactic methodology that creates the capacity to apply information to genuine world issues and circumstances, and to look for and evaluate diverse sources of data in order to solve the problem being studied. For these reasons, it is seen as a reasonable methodology for ESD [31,32]. It expands conceptual knowledge and problem-solving abilities.

It helps students to acquire new concepts and critical thinking abilities, which are learned in application to real life situations. Students obtain information and gain knowledge, while getting familiar with the dilemmas faced when applying or producing innovative solutions for interdisciplinary sustainability issues. This facilitates the comprehension of the wider picture and the association between various sustainability spheres such as the natural, social, economic and political [33,34]. It elevates the capacity to figure out how to learn, to foster cooperation abilities and interpersonal competencies for satisfactory professional performance. Problem-based learning may likewise converge with case studies as a type of inquiry-based learning [18].

Case studies have been commonly used in several areas of study and in modules that are not sustainability focused. This methodology boosts understanding of the topic and the system as a whole, taking into account its complexity and multiple interconnections. Case studies are real and context-oriented, a characteristic that allows learning from real practice and situations, and the establishment of solutions taking into account different stakeholders [4]. Deep descriptions and analysis of real-world scenarios, problems and debates in sustainability can help students to acquire the skills that allow them to handle intricacy and incertitude at the community, regional and global levels [35]. Case studies allow students to engage in research, to examine real-world examples contemplating the perspectives of diverse partners and to encounter the complexity of socio-environmental systems [18,36].

Simulations or role-playing games are a didactic strategy that foster experiential learning. Students become characters and have to reproduce a context or situation close to real life [27]. It includes acting and dramatisation, the sharing of views and feelings with others and reflection on the subject or subjects involved. Simulation games are valuable tools for the analysis of social, economic and environmental problems in all of their facets, including methodological, institutional and historical, amongst others.

Cooperative or collaborative inquiry comprises learning through researching with other people, hence student groups and stakeholders engage in a research process, where all of the research decisions are shared by peers who become co-researchers [37]. Establishing an effective communication and exchange, and positively collaborating with the group members of the cooperative team, is critical to foster the sustainability competencies that enable the building of a more environmentally friendly community and sustainable future. The engagement of multiple partners and stakeholders, active engagement and collaboration, and inquiry with the community help to foster the development of sustainability competencies [12].

2. The Smart Classroom

Smart Learning Environments (SLE) comprise, in a conscious and strategic way, the use of technologies within learning environments to allow a positive impact on the students' learning experiences. Huang et al. define an SLE as "the learning place or an activity space that can sense learning scenarios, identify the characteristics of learners, provide appropriate learning resources and convenient interactive tools, automatically record the learning process and evaluate learning outcomes in order to promote effective learning" (p.8) [38]. According to Koper, an SLE must be enriched with digital, adaptive and environment-aware devices in order to promote faster and better learning [39]. Other authors also point out the customisation of adaptive teaching and learning by means of technology to obtain better results for both learning and teaching conditions [7,40,41].

In the 21st century, SLEs have to be understood in a holistic way to support ubiquitous learning, as people now learn at any time and from anywhere. In particular, Smart Classrooms are the physical spaces created to cope with this new paradigm. Therefore, a Smart Classroom has to take into account the personalisation of all processes to offer a more effective scenario for both group and individual tasks [42,43]. It also considers inclusion, to ensure that all of the students have the same chances regardless of their skills and competencies [44], and the sustainable use of resources and the infrastructure itself [45–47]. A complete conceptualisation of SLEs and Smart Classrooms offered by Palau & Mogas identified three dimensions that must coexist in such spaces: technology,

environmental factors and the processes carried out [48]. These dimensions are interrelated and nailed down in eight categories of characteristics (Figure 1).

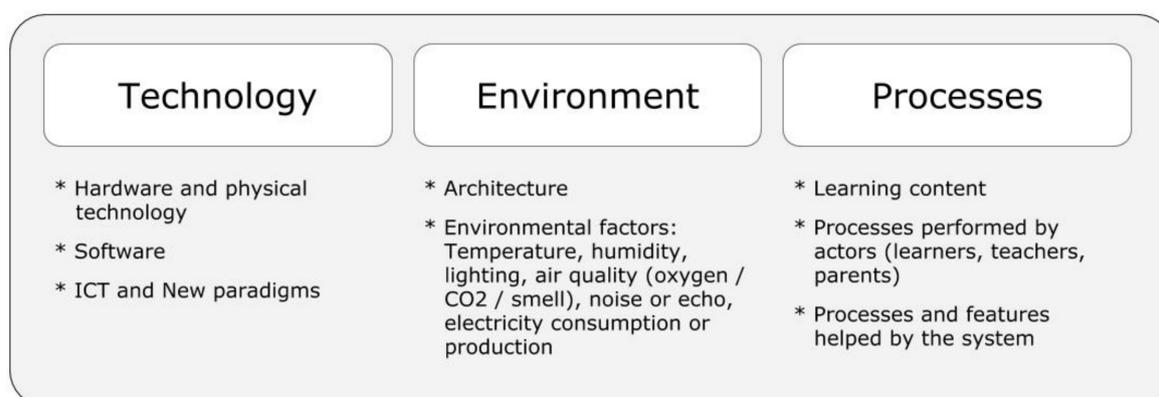


Figure 1. Dimensions and categories of characteristics in a Smart Classroom. Adapted from Palau & Mogas [48].

2.1. Technological Solutions

Technology in a Smart Classroom is understood in a broad sense, as it includes digital and mobile devices, sensors and recognition systems, learning management systems and other software, jointly with the introduction of modern paradigms like cloud computing, big data, learning analytics, Internet of Things, artificial intelligence, and augmented and virtual realities, amongst others [48].

Digital and mobile devices may include smartphones, tablet PCs, touch screens, interactive tools and whiteboards. These devices must be completely integrated in the Smart Classroom: a smart/interactive whiteboard [49], a smart system as an “e-podium” to allow students to draw annotations live in the teacher’s digital material [50], a system to allow interaction with screens through body movements using somatosensory equipment [51], and multiple student-controlled interactive whiteboards or touch screens [52]. Some devices can be brought to the Smart Classroom according to the Bring Your Own Device (BYOD) initiative, promoting the use personal devices by students. It is increasingly common to find wearable devices, such as smart watches, brainwave detection, and emotion recognition [53,54].

Sensors and recognition systems can be as easy as using a wearable radio-frequency identification (RFID) tag sensor to control attendance [55]. Sensors can monitor the environmental factors inside the room to provide input on the convenience to adapt air quality (e.g., to renew air when CO2 exceeds the recommended limit), temperature, lighting and acoustics, amongst others. Sensors also allow voice detection and recognition, facial recognition, eye-tracking and motion tracking [56], or the checking of whether the student is sitting down or not, using pressure-sensitive sensors [57]. Sensors can also be placed inside the devices such as smartphone cameras [58].

Software can promote the greater personalisation of the learner experience. Basic software includes learning management systems, which can complement books and teachers’ guidance and supervision. Specific software can also be developed to enrich Smart Classrooms. For example, Pirahandeh & Kim present their Smart Classroom storage management system (SCSMS) [59]; Li, Du and Ma show the Smart Learning Partner (SLP) platform as a smart service [60]; and Jormanainen, Toivonen and Nivalainen explain the platform HiljaNet [61], a learning environment based on a distributed sensor network that includes in-building automation and the measurement environmental conditions [61].

From the newest perspectives on technology evolution, cloud computing is being increasingly introduced in smart learning environments [62]. Cloud computing allows students to work collaboratively in the virtual space, having all of the content actualised, shared and accessible anytime, so it becomes easier to interact with in learning processes. The data collected through cloud computing provides teachers and students with the opportunity to reflect on the learning and

experience and to develop improvements for further teaching practice. These data may be gathered using sensors, cameras, computer systems or other tools, and learning analytics can be used to analyse them [63]. Internet of Things (IoT) is closely related to wearable technologies [64] and connects every object on the room to the server or internet, allowing data collection and processing [65].

Other devices and technologies are being introduced in education. The newest developments include augmented reality and virtual reality, which can provide immersive scenarios to make learning more interactive and suitable because it is focused on a learner-oriented application [66].

2.2. Environmental Conditions

The environment in a classroom affects the learner's progress, mood, comfort and concentration capacity. From the outlook of a Smart Classroom, it is necessary to control lighting (correlated colour temperature, intensity, light dazzles, etc.), acoustics (reverberation, noises from outside and inside, teachers voice, etc.) and air quality (CO₂, temperature, humidity, etc.). As part of the environment, there is also the architecture and functional design of the learning space.

Classrooms can be lighted using natural and/or artificial light. Both are well accepted, but the former is not modifiable whereas the latter can be adapted to different needs. Namely, light must provide the appropriate intensity and correlated colour temperature according to the activity performed in classroom in order to promote a more suitable atmosphere for learning. Especially, the correlated colour temperature should be adapted to different situations, ranging from lower warm lights in group work and relaxed activities to colder blue light to maintain attention in lectures and exams [67,68]. An ideal Smart Classroom should predict the lighting parameters for each learning situation; by this point, there are systems that allow the teacher to control a dynamic lighting system [69].

Acoustics must also be considered to control reverberation time [70], and noises from outside [71] and inside the classroom [72]; to avoid echo effects [73]; and to improve sound quality in general [74]. These aspects directly affect the student learning process. Particular cases are those of deaf and hard-of-hearing students [75] and learners with autism [76], amongst others. All of these must encounter a suitable acoustic environment within a Smart Classroom, with facilities to cope with their particularities. In addition, a teacher's voice might be hurt if the room acoustics force unusual vocal efforts [77]. This is a problem that is currently being studied and can be overcome with innovative technological solutions.

Controlling the air quality is essential in a Smart Classroom. The existing literature shows that high amounts of CO₂ have a negative effect on students' attention [78]. Air quality is also related to oxygen levels, the carbon dioxide concentration, smell, and even the existence of gases or volatile organic compounds (VOC). Temperature and humidity are related to the air quality. The Smart Classroom must guarantee a desirable range of these parameters, because if the space is too hot (or too cold) the concentration capacity of students decreases [78].

The architecture and functional design in a Smart Classroom must ensure the capacity to integrate systems to self-regulate all of the environmental factors mentioned above [79], and to allow an ecosystem to enable greater personalisation for learners [80]. It is also essential to respect the basic principles of sustainability. A growing number of architectural projects focus on the promotion of green materials for sound absorption [81] and reducing energy consumption [61,82].

2.3. Performed Processes

Three agents can carry out processes in a Smart Classroom: teachers, students and the system. Parents could be seen as a related agent, but they do not have a clear involvement within the classroom setting. Therefore, the system (all what happens in a Smart Classroom from the technological perspective) must help the other actors: students and teachers.

A Smart Classroom must be enriched with technology to accomplish the following attributes: personalisation and customisation of the learning, feedback provision, self-regulation and autonomy, context awareness and connecting capabilities. Ease of use, effectiveness and efficiency of the systems

have to be considered to offer feasible solutions of technology-enhanced Smart Classrooms; otherwise, technology would instead be a complication for its users.

A basic feature of a Smart Classroom is the ability to adapt itself to student needs [63] in terms of the curriculum, course content, strategy and support [54,83]. It has been broadly accepted that personalisation and customisation must be supported by the Smart Classroom: smart systems should track the evolution of each individual, or at least the students should be able to customise their path according to their own learning profile [43].

Feedback provision goes a step further in the personalisation of learning processes. It is not limited to self-corrections of closed questionnaires, but real-time recommendations to the students [54] and intelligent tutoring systems [84]. Feedback can also be reported to the teacher informing them of the overall students' moods, giving advice on non-verbal behaviour [53] or other inputs to make teaching more efficient.

Smart learning is a self-directed, human-centred learning method [85], which allows student self-regulation to foster autonomous and lifelong learning. On the other hand, self-regulation also means the capacity of the system itself to adopt different solutions according to different learning situations. System self-regulation is studied in automation processes, as it refers to the capability of the system itself to make decisions.

By means of context awareness, students can be provided with task-relevant information combining the physical classroom with virtual learning environments [54]. Context awareness is one of the elementary features of the smart learning environment definition [39], which is in line with the need for the personalisation of learning in classroom settings.

Connections between people are elementary, as interaction is the core of smart learning [80], including the relationships between students [52], interactions between teachers and students, or even connections between the actors and the objects and spaces (IoT), and between human-computer interactions and buildings [86]. The Smart Classroom must allow all kinds of interactivity and interconnections.

A Smart Classroom must be effective and efficient, allowing the best conditions for teaching and learning to take place [49], and must be easy to use to avoid the actors being discouraged due to technical issues [52]. A Smart Classroom must also be engaging and motivating [87]; this does not only depend on the system, but also on how actors behave and interact, and their willingness to make the most of the space.

Different approaches have been published regarding the actors, which include Smart Classrooms founded in the constructivist epistemology [52], and focusing on connectivism and building learning and teaching communities [51]. In any case, Smart Classrooms demand adaptation to a new learning paradigm [88], new pedagogies and new teaching methodologies for smart citizens of the 21st century, and the development of new skills and competences [83].

Currently, the trends on teaching and learning in Smart Classrooms tend towards cooperative inquiry and collaboration amongst students, as well as experimentation, problem- and project-based learning, and learning by doing [48]. Therefore, the Smart Classroom allows such a flexibility and adaptability of the learning space that methodologies for the development of ESD competences can easily be adopted.

3. Methods

As stated in the Introduction, the aim of this paper was to establish how Smart Classrooms can contribute to the putting in practice of ESD methodologies in an effective way. The starting point was the selection of a set of four ESD methodologies based on the criteria of its wide use and recognition in the literature and by the ESD community as to lead to the development of sustainability competencies: project or problem-based learning, case study, simulation and cooperative inquiry.

The method used in this study consisted of a literature review of both theoretical frameworks separately, ESD and Smart Classrooms, and a subsequent expert analysis to identify the interrelation

between both. The authors performed the analysis and connected Smart Classrooms and ESD rationales through an iterative discussion process and triangulation between them, as experts of both disciplines. One of the authors is an expert in ESD, and two are experts in Smart Classrooms.

The expert analysis of the ESD methodologies in relation to Smart Classrooms was conducted using the conceptual framework of Smart Learning Environments developed by Palau and Mogas (see Figure 1), which identifies three dimensions and eight categories of characteristics of Smart Classrooms [48,89]. Apart from dimensions, the authors pointed out the need to deal with categories of characteristics rather than with characteristics themselves. This is because whereas categories are considered fixed, some of the characteristics might evolve and depend on technological or social advancements and, therefore, either these could become outdated or new characteristics might emerge in the future.

Each ESD teaching and learning method was analysed separately and was positioned for each of the eight categories of characteristics identified in a Smart Classroom, in relation to its level or degree of adequacy (from low to high). Moreover, based on the literature review conducted and the results of the expert analysis on how the selected ESD methodologies match with the dimensions and categories of characteristics of the Smart Classroom, a set of suggestions and recommendations were built to help advance the implementation of ESD methodologies with the support of the Smart Classroom.

4. How the Smart Classroom Can Contribute to Education for Sustainable Development

4.1. Relationship between Smart Classrooms and ESD Methodologies

To conduct the expert analysis and determine the relationship between the Smart Classroom's categories of characteristics and the four selected ESD methodologies, the authors used the following codification. The characteristics related to the dimension of technology were grouped into three categories: hardware and physical technology (T-h), software (T-s), and ICT and new paradigms (T-p). The characteristics associated with the environmental factors dimension are included in architecture (E-a) and environmental conditions (E-e). The characteristics of the processes dimension are organised according to three categories: learning content (P-c), processes performed by actors (learners, teachers and parents) (P-a), and processes and features helped by the system (P-s).

The relationships established between these categories and ESD methodologies are presented in Table 1 according to three degrees of ESD methodologies' facilitation and development:

Table 1. Relationship between the dimensions and categories of characteristics in a Smart Classroom, and Education for Sustainable Development (ESD) Methodologies.

	Technology			Environment		Processes		
	T-h	T-s	T-p	E-a	E-e	P-c	P-a	P-s
Project or problem-based learning	H	H	H	H	H	H	H	M
Case study	H	H	H	H	H	H	H	M
Simulation	H	H	H	L	M	H	M	H
Cooperative inquiry	H	H	H	H	H	H	H	H

H = High, M = Moderate, L = Low.

The dimension of Technology and its associated characteristics are highly related to all of the ESD methodologies studied, because the current technological developments are widespread and allow the adaptation and usage of student-centred methodologies. Technology is basic in Smart Classrooms as a means to covering pedagogical needs [89]. The dimension of Environmental conditions also shows a high level of relation for all of the ESD methodologies except Simulation. Indeed, Simulation is the ESD methodology presenting the weakest relationship with the different categories and dimensions of Smart Classrooms. This can be explained because architecture presents a great challenge in order to design and adapt learning spaces to simulations, which are more commonly held in online or virtual settings [51]. The dimension of Performed Processes is the lowest scored category, mainly regarding

two categories: processes performed by actors (learners, teachers and parents) (P-a), and processes and features helped by the system (P-s). This can be justified because Smart Classrooms are physical spaces endowed with digital devices to ease processes, but teachers and learners are the ones that must drive learning situations and, as a consequence, they must have the digital competences and the ability to manage advanced solutions [90]. Moreover, in reference to project or problem-based learning and case study, these are open methodologies where the system needs a high level of technological development in order to provide proper feedback. According to previous studies schools often present difficulties to implement advanced technologies [89]. In this context, the Smart Classroom can help progress the embedment of technology in educational settings to improve teaching and learning process in accordance to teachers' and students' needs.

Focusing on the four ESD methodologies analysed, the following bullet points summarise how each relates and can be developed within Smart Classrooms:

- **Project or problem-based learning:** Highly related because it promotes the ability to learn how to learn, to develop teamwork and professional skills. Smart Classrooms provide and promote the spaces and conditions for developing teamwork with the right environmental conditions of light, acoustics, furniture, devices, connection and collaborative tools [48]. Smart Classrooms allow students to access the worldwide knowledge, while a critical analysis of different sources of information is promoted. At the same time, it is a space for debating and for knowledge co-creation and sharing. The space can be adapted to student groups' needs.
- **Case study:** As with the project or problem-based learning methodology, case study is highly related with Smart Classrooms, but more in terms of the personalisation of learning and the promotion of autonomous learning [43,51,54]. Smart Classrooms create the ideal space for qualitative research, with learning spaces to discuss and collaborate [43,86]; and use specific or non-specific qualitative tools such data analysis software, which allow working on qualitative data such as responses from interviews or focus groups. In this learning environment, experts or informants on the topic studied can be invited to share their knowledge and give their opinion on the problem or situation being studied. This can be held in a physical space or by videoconference [49]. Smart Classrooms also create the conditions for having debates, presentations and group discussions.
- **Simulation** can take place in a physical or virtual environment. One interesting point of this methodology is that it can be carried out on virtual scenarios or platforms in order to simulate situations that cannot be held in the classrooms. Another option is using virtual labs. Educational labs have a high cost for schools. This includes the initial cost of acquiring them, followed by the maintenance cost. In the present day, projects as Golab [90], give the students the opportunity to use a virtual laboratory in order to learn scientific knowledge from practice [91]. Previous initiatives have also looked for new methodologies to ease the process of migrating from classic laboratories to web-based labs [92], although this is not framed in virtual simulation but physical switch. Another perspective are the simulation games or role-playing games in the classroom. They are perfectly suitable in a Smart Classroom because all of the environmental conditions and furniture can be adapted to meet the situation simulated.
- **Cooperative or collaborative inquiry** involves research in collaboration. It fits perfectly in a Smart Classroom because both research and collaboration are two of the intrinsic goals of smart learning environments. It should be noted that in a Smart Classroom, the access to the knowledge is a priority, as is the use of collaborative tools and interactive spaces for working, debating, sharing, exposing and presenting ideas. An implemented solution is the pad-based multi-device collaborative teaching software architecture for Smart Classrooms, a distributed collaborative learning environment to boost communication and collaboration, including students' inquiry-based learning and cooperative learning (which is under the control of the teacher's pad), and teaching and learning activities [93].

4.2. Contributions of Smart Classrooms to ESD

Through the reviewing of the existing literature and the conducted expert analysis, a set of suggestions are made to help achieve ESD with the support and use of Smart Classrooms. From the relationships established above in Table 1, different ways in which Smart Classrooms can contribute to the performance of ESD methodologies have been identified (Table 2). These ways are presented according to the three main dimensions of Smart Classrooms: technology, environmental conditions and processes.

Table 2. Suggestions about how Smart Classroom dimensions could contribute to the performance and development of the ESD Methodologies.

Technology	Environment	Processes
Access to knowledge. Collaborative management project tools. Cloud storage with easy access and management of the information from everywhere and all the devices. Collaborative data software tools. Collaborative writing tools. Virtual science labs allow students to conduct difficult experiments that cannot take place in real labs. Mobile devices with large battery duration and easy management. Smart walls where students can write, present and share information. Sensors for measuring biodata and cognitive processes in students and teachers.	Acoustics adapted to spaces that need to mix silence, debates, discussions, brainstorming and oral presentations. Smart oxygen control for seminars and lectures of more than one hour. Energy consumption efficient spaces. High performance of natural lighting system combined with the artificial ones. Smart lighting adapted to different spaces and tasks at the same time and at real time. Flexible furniture adapted to different types of students' task and able to work with mobile devices. Temperature control that assures the right parameters for learning. Colours of the space adapted to the needs of students according the type of activity and student needs.	New resources that allow the development of ESD competences. Activities and resources designed specifically for any methodology. Allow parents and teachers to be involved in the learning process. Collaboration and cooperation between students. Experimentation with labs that are currently not available in classrooms. Sharing knowledge and learning with others. Sharing and co-creation of sharing knowledge. Creativity and knowledge management. Teaching and learning in sustainable and resource efficient spaces lead to sustainable learning. Monitoring of cognitive processes to make faster and evidence-based teaching and learning decisions.

According the current state-of-the-art of technology and the latest technological developments, we outline a set of actions that educational institutions can undertake to implement Smart Classrooms to put ESD methodologies into practice. We distinguish between actions that can be implemented immediately, and actions that could be implemented in the short, medium or long term depending of the level of technology development. It should be considered that the cost of technology is always high at the beginning, and lower over time. This is the reason why we have not taken into consideration the cost for this analysis (Table 2). Only the current technological development status was considered.

In the short term, new developments should go in the direction of allowing a new learning paradigm [88], new pedagogies and new teaching methodologies for smart citizens of the 21st century, and for developing new skills and new competences [83]. Concerning technology, the implementation of Smart watches or RFID tag sensors for teachers and students [53–57,64], interactive whiteboards or touch screen displays with multiple students [49,52] or interaction screens that recognise body movements [51,52], and full access to knowledge through mobile devices and full internet access can be considered. It should be noted that there are existing initiatives and solutions of cloud storage [59,62] allowing easy access and information management from anywhere, and devices with collaborative data and writing software tools that allow knowledge sharing, management and co-creation [66], considering students' needs [63] and student-centred learning methods [85], which allow student self-regulation to foster autonomous and lifelong learning. These software solutions will permit parents and teachers to be involved in the project and learning process at any time [66]. In terms of the environmental conditions, solutions of oxygen control for seminars and lectures of more than one hour are needed [78]. Energy consumption respectful spaces [61,79,82]. High performance of the natural lighting system combined with the artificial one. Flexible furniture adapted to different types of student tasks and which allow working with mobile devices [79]. Temperature control that ensures that the temperature is between the right parameters for learning [67–69]. Finally, new contents and teaching and learning resources should be launched that help in the process of developing ESD competences and personalised learning [43,54,80,83].

In the medium term, collaborative management project tools adapted to learning projects could be implemented [66]. Virtual science labs [66] that allow students to conduct difficult experiments that cannot take place in real labs, as has been argued in this paper. Experimentation with physical labs, which are currently not available in traditional classrooms, should be fostered. Concerning devices, the needs that have to be solved in the medium term are the battery duration and easy management for IT administrators and teachers. In relation to the environmental conditions, lighting could be smart, adapted to different spaces and tasks at the same time and in real time [78,79]. Additionally, acoustics can be smart, adapted to spaces that need to mix silence, debates, discussions, brainstorming and oral presentations [70–74,77,81]. The colours of the learning spaces have to be adapted to student needs according the type of activity, at the same time that Smart walls permit students to write, present and share ideas and knowledge [49,52].

The long run is more centred on taking data and using Artificial Intelligence [63,65]. Sensors could measure and monitor the students' and teachers' cognitive and behavioural processes [53,54,56]. It will be a real revolution because the system will provide real time information [54,84] and will help teachers to make fast decisions to conduct and adjust the students' learning pathways [65,80] and student-centred learning methods [85], which will allow student self-regulation to foster autonomous and lifelong learning. Artificial Intelligence will probably provide possible or alternative solutions based on the data analysis of the learning profiles of students and their interaction with the learning environment [65].

5. Conclusions

A key issue and trend related to ESD is the changing of learning environments to allow ESD methodologies. Learning environments have to be adapted to apply a whole-institution approach and the principles and philosophy of sustainable development [6]. In this context, Smart Education gains force as a means to put into practice ESD processes as it creates intelligent, sustainable, resource efficient, personalised and adaptive learning environments [7].

In this study we have reviewed how Smart Classrooms can contribute to putting into practice ESD methodologies in an effective way. According to the literature review, three dimensions of a Smart Classroom were considered to conduct the analysis: technology, environmental factors and performed processes. The technology dimension highly facilitates the put in practice of ESD methodologies, because it allows the use of a wide range of tools assisting the teaching and learning process and allowing the adaptation to teachers' and students' needs. Environmental factors such as lighting, acoustics and air quality have an impact on student learning and concentration ability. The environmental factors dimension is highly related to all ESD methodologies except simulations, as these provide better conditions for learning in a comfortable and pleasant learning environment. Simulations showed a lower level of relation to environmental conditions due to the fact that these are mainly held online or virtually, therefore the physical environment does not have a direct impact on learning conditions. In terms of the performed processes dimension, a lower relationship was determined for all the ESD methodologies studied. This is due to the fact that Smart Classroom provides the physical environment, but the ones in charge of leading the teaching and learning processes are the teachers and the students. There are other factors such as the digital competencies of teachers and students, the autonomous learning ability of students and the educational innovation capacity of teachers that are out of the scope of the physical space provided by Smart Classrooms and that influence its effectiveness.

For each of the ESD methodologies studied, the level of adequacy of the Smart Classroom to facilitate its implementation has been determined. Smart Classrooms show a high level of adequacy for using problem and project-based learning, case study and cooperative inquiry methods because of their characteristics in terms of technology developments, environmental conditions and performed processes. The Smart Classroom enables collaboration, the access to and exchange of information, knowledge sharing and successful interaction between students and teachers, leading to an effective

implementation of ESD processes and methodologies. Conversely, Simulation is the ESD methodology which showed the lowest level of adequacy with the Smart Classroom. The Smart Classroom is a physical environment, while simulations in education tend to be held online rather than through face-to-face interactions, mainly due to economic constraints.

It is necessary to implement innovative methodologies that help reframe the learning environment towards ESD. As shown by the results of this analysis, the Smart Classroom has the characteristics to contribute to more personalised and autonomous learning. Additionally, as stated in the previous section, recently conducted research shows that blended-learning and other innovative methodologies such as flipped learning, web-based laboratory practice and visual learning are successful tools to move from classic teaching and learning to web-based labs and autonomous learning [92].

One of the limitations of this study is that in the conducted expert analysis, we conceived the Smart Classroom as a space that copes equally with any type of student at any education level. It should be noted that some differences might exist; thus, further empirical research is needed to report on the real effects when using Smart Classrooms with different type of learners, identifying students' and teachers' needs and different education levels.

As the Smart Classroom is a relatively new and emerging research area, in early development, it is a challenge to offer concrete specifications and evidence of its application. In addition, the investment and technical development can also represent a contextual limitation in different regions and countries. Due to these constraints, the creation of Smart Classrooms is still in its infancy, with a limited number of these learning environments worldwide. It is essential to create such learning spaces to empirically explore their impact on the development of student-centred teaching and learning methodologies. Thus, little evidence exists regarding the impact that Smart Classrooms have on the development of sustainability competencies. Further empirical research is needed to explore the influence that the Smart Classroom has in enabling ESD processes and practices.

It must also be acknowledged that the physical environment—the Smart Classroom—is fundamental for rethinking learning, but its effective implementation also depends on the teaching competences and the digital competences of educators [90]. Therefore, teacher training programmes focused on the correct use of the Smart Classroom and on developing digital competences amongst educators are critical to its successful implementation.

Six key implications for action to create Smart Classrooms that assist the progress of ESD are drawn from the literature review and expert analysis conducted. These include actions that can be implemented immediately and in the short, medium and long term to facilitate ESD Smart Classrooms:

- Experimentation with virtual labs in classrooms that allow students to conduct difficult experiments, which can give students the opportunity to gain scientific knowledge from practice.
- The creation of learning environments that use resources efficiently: sustainable energy consumption and the smart control of temperature that ensures that it is between the right parameters for learning.
- The use of sustainable mobile devices with large battery durations, easy and fast recharging, and remote management.
- Putting in place flexible and versatile furniture that facilitates different types of task and the use of mobile devices such as smart walls, where students can write, present and share ideas, and co-create knowledge.
- Assuring optimal environmental conditions for learning. Air quality control (e.g., oxygen levels), a natural lighting system combined with dynamic artificial lighting adapted to different spaces and tasks at the same time and in real time, and smart acoustics controls adapted to spaces that need to mix silence, debates, discussions, brainstorming and oral presentations.
- The innovative use of ICT in education such as with collaborative and cooperative tools for students, teachers and parents; collaborative management project tools; cloud storage with easy access to manage information from anywhere and all of the devices; collaborative data software tools and collaborative writing tools that allow knowledge sharing.

Furthermore, to rethink and redesign learning spaces for ESD, it is essential to develop smart learning environments that are flexible and sustainable themselves. This involves creating learning spaces that allow an efficient use of resources, the creation of optimal environmental conditions, and the innovative use of ICT and the adaptation of furniture to engage students in real ESD processes and help them to develop sustainability competencies.

Author Contributions: The authors have equally contributed to this work, conceptualising and designing the study, conducting the literature review and expert analysis, discussing results and drawing conclusions. All authors have read and agreed to the published version of the manuscript.

Funding: This research was partially funded by the Secretaria d'Universitats i Recerca del Departament d'Economia i Coneixement de la Generalitat de Catalunya, the European Union (EU) and the European Social Fund (ESF), grant number 2017 FI_B 00085.

Acknowledgments: Gisela Cebrián is a Serra Húnter Fellow.

Conflicts of Interest: The authors declare no conflict of interest.

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