INTEGRATING SUSTAINABLE DEVELOPMENT IN A COMPUTER SCIENCE PROGRAM: A REVIEW

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ABSTRACT

The Computer Science program of the School of Engineering at the Universidad Católica de la Santísima Concepción is working to adopt CDIO Optional Standard 1: Sustainable Development and cover sustainable development in an integrated manner in the current study plan. Hence, we wish to know which strategies have been applied to promote sustainable development in Computer Science, both at the curricular and pedagogical levels. To answer this question, we performed a review of relevant peer-reviewed articles and conference papers retrieved from online databases. Even though our focus is Computer Science, we expanded our search to consider Information Technology, Information Systems, Informatics, and other STEM programs, as many strategies for these fields are similar and thus their results are also applicable. Our preliminary results show that, in general, sustainable development in Computer Science has been approached at the curricular level and at the pedagogical level. In the first case, programs define the competences, knowledge, skills, and attitudes required to address sustainable development challenges. However, there is no clear consensus on which specific competences, skills or knowledge should be included in the curriculum, nor when and where they should be addressed. At the pedagogical level, the literature on sustainable development education shows that, while some higher education institutions still favour traditional lecture-based courses, active learning methodologies are the prevailing trends. Among the works reviewed, we find many examples of problem-based learning, project-based learning, game-based learning, challenge-based learning, case studies, and debates being used. The main contribution of this work is to serve as a guide in integrating sustainable development in a Computer Science program by defining program goals and learning outcomes related to environmental, social, and economic sustainability for our Computer Science curriculum reform process. Furthermore, this work can contribute to the selection of appropriate pedagogical approaches to sustainability teaching and learning.

KEYWORDS

Computer science, Sustainability, Standards: 2, 3, 7, 8, 9, 10 Optional standards: 1

INTRODUCTION

The Computer Science program of the School of Engineering at the Universidad Católica de la Santísima Concepción is facing a curricular reform process. Among its goals is the adoption of CDIO Optional Standard 1: Sustainable Development, which in a recent self-assessment process was evaluated at an achievement level of 1 in the CDIO rubric for that standard (Martínez-Araneda et al., 2022). Currently, the Computer Science program includes a mandatory course on Environment and Energy, and students usually work on projects focused on the UNDP Sustainable Development Goals in their first-year introductory course projects and in some latter-year projects, but sustainable development is not covered in a systematic and integrated manner in the current study plan. Our medium-term goal is to reach an achievement level of 3 in the CDIO rubric for the Sustainable Development standard: *There are explicit program goals and intended learning outcomes related to environmental, social, and economic sustainability and at least three substantial sustainable development learning experiences of increasing complexity including an introduction early in the program* (Malmqvist et al., 2020).

The UN defines Sustainable Development *(SD)* as *development that meets the needs of the present without compromising the ability of future generations to meet their own needs* (Brundtland, 1987). On the other hand, UNESCO states that Education for Sustainable Development (ESD) *gives learners of all ages the knowledge, skills, values, and agency to address interconnected global challenges including climate change, loss of biodiversity, unsustainable use of resources, and inequality. It empowers learners of all ages to make informed decisions and take individual and collective action to change society and care for the planet. ESD is a lifelong learning process and an integral part of quality education. It enhances the cognitive, socio-emotional, and behavioural dimensions of learning and encompasses learning content and outcomes, pedagogy, and the learning environment itself* (UNESCO, 2022). Moreover, the UN 2030 Agenda for Sustainable Development defines its target 4.7, Education for sustainable development and global citizenship as: *By 2030, ensure that all learners acquire the knowledge and skills needed to promote sustainable development, including, among others, through education for sustainable development and sustainable lifestyles, human rights, gender equality, promotion of a culture of peace and non-violence, global citizenship and appreciation of cultural diversity and of culture's contribution to sustainable development* (United Nations, 2015).

Sustainable development has been a peripheral subject in most computing-related engineering programmes. In particular, computing-related programmes in Chile are rather inflexible giving students little leeway to take optional credits in other areas of interest. In our experience, the latest generation of computer science students are more aware and concerned about sustainability issues such as global warming and climate change but find it hard to relate these concerns to current computing competences. For example, there is little discussion of the effects of IT on the environment and its carbon footprint is not covered in the curriculum. The challenge for our curricular reform process is, then, how to incorporate these topics into the curriculum, balancing sustainable development at a general level versus as it specifically relates to computing. At the same time, it must handle the tension between teaching SD facts versus an emphasis on students' reflections and/or practicing skills (Eriksson, 2016).

In this work, we present the results of a literature review aimed at identifying what kinds of strategies have been applied to promote sustainable development in computing-related engineering programs, both at the curricular and pedagogical levels.

REVIEW METHODOLOGY

We performed a narrative review (Bearman *et al*., 2012) of relevant literature retrieved from online databases. Our inclusion criteria are articles focusing on higher education, published in journals and conference proceedings either in English or Spanish. Our exclusion criteria discarded articles published before 2007, the year of the School of Engineering's major curricular reform for all its programs where the CDIO approach was adopted. The search was limited to peer-reviewed articles and conference papers in full text, extracted from databases such as the Wiley Online Library, Elsevier ScienceDirect, the CDIO Digital Library, and the ACM Digital Library, among others. Even though our focus is Computer Science, we expanded our search to consider Information Technology, Information Systems, Informatics, and other STEM programs, as many strategies for these fields are similar and thus their results are also applicable.

Our research questions focus on integrating sustainable development into computer-related engineering programs regarding the curriculum and those pedagogical strategies used to acquire different competency levels. Thus, our research questions are:

Research Question 1: What concrete actions have been taken to include sustainability in computing-related engineering program curricula?
Research Question 2: Which active learning experiences have been applied to aid the development of the SD competence in students?
Research Question 3: Are these ESD learning experiences at an introductory, intermediate or advanced complexity level?

RESULTS

The above-mentioned databases were consulted using the search terms "Sustainability" and "Sustainable Development", and "Computer Science", "ICT", "Computer Technology", "STEM", "Engineering Education", among other similar terms. These results were then reviewed and filtered to yield 57 articles, which were then analysed to answer our research questions. In this literature review, we aim for a qualitative rather than a quantitative analysis. In the following sections we present our principal results for our research questions.

Results for Research Question 1

To analyse our findings for the first research question, we find it useful to refer to the degrees of sustainability integration into the curriculum presented by Huntzinger et al. (2007): at the first level, "Bolted On", sustainable development is acknowledged in the goals or mission statement of the program, but there is limited integration in courses or in the curriculum. For example, sustainable development might be present in one course or as a module in several courses at the junior or senior level. At the next level, "Built-in", SD is integrated into the goals and mission statement of the program and significant effort has been made to integrate concepts and methods into the existing curriculum at all levels. At the highest level, "Redesign", sustainable development has become an essential element of the program goals and significant effort has been made to rethink and redesign and program to completely integrate concept into the curriculum at all levels.

Most of the articles included in our sample, with a few exceptions, present approaches that fall into the "Bolted-On" category: sustainable development is included into computer science programs as modules in specific courses or as a special course dedicated to the topic in an study plan otherwise lacking any other coverage of sustainable development, or at least, the

information provided by the authors does not allow us to infer otherwise. For example, Cai (2010) has created specific green computing modules that can be added to other CS courses; Cayzer (2010) discusses designing sustainability units for courses in the Innovation and Technology Management MSc at Bath University; Abernethy and Treu (2014) describe how they added a self-contained one-week module on sustainability to the Introduction to Information Technology course about IT's role in sustainable development; Hilty and Huber (2017) discuss lectures given as part of an Informatics and Sustainable Development course and as guest lectures in the courses "Sustainable Development for Computer Science and Engineering" and "Sustainable Development, ICT and Innovation". Stone (2019) has created sustainable development projects to be incorporated as modules in five other courses. Likewise, Cai (2010) developed a Green Computing and Network Services course, Eriksson et al. (2016) describes three introductory courses on sustainable development in three different ICT-related programmes at KTH. Fisher, Bian and Chen (2016) also provide several examples of computing courses related to sustainability.

In our sample, an example of the "Built-in" approach is the work of Gimenez-Carbo *et al.* (2021), which presents a study on the development of the cross-curricular learning outcome (CCLO) "Ethical, environmental and professional responsibility" for students of different bachelor's degrees taught at the Universitat Politècnica de València, Spain. In particular, this learning outcome is covered in three compulsory courses and two optional courses of the bachelor's degree in Telecommunication Technologies and Services Engineering, via case studies, gamification and simulation.

In our review, many authors discuss the need for a comprehensive curricular redesign to incorporate SD into a study program under institutional guidance and support. Nuñez et al. (2020) present an "Redesign" exemplar: a case study on integrating sustainable development into a bachelor's degree curriculum at the Tecnológico de Monterrey, Mexico. This curriculum reform was designed to incorporate design project courses ranging from the 3rd. to 9th. Semester of studies and includes sustainable development content at every level.

Results for Research Question 2

Our literature review shows a great diversity in the active learning pedagogical strategies used in education for sustainable development, with project-based learning and reflective activities being the most prevalent. In the following sections, we present an incomplete list of examples for common pedagogical strategies used in ESD.

Project-based learning

Works by Weber et al. (2014), Eriksson *et al.* (2016), Marasco *et al.* (2016), Stone (2019), Gimenez-Carbo *et al.* (2021) all describe applying project-based learning in introductory courses incorporating sustainability themes.

Games-based learning

Game-based learning is a pedagogical strategy that is very appealing in computer-related programmes, as it encourages student engagement and reflection. Eriksson *et al.* (2020) uses systems thinking games in an introductory course on sustainability and media technology. Swacha *et al.* (2021) make the case for the effectiveness of using game-based learning for sustainable development education, and describe Eco JSity, an interactive educational game for solving classic algorithmic problems with JavaScript code, whose storyline, game space,

and rules are all themed around sustainable development. Gimenez-Carbo *et al.* (2021) also describe the development of the cross-curricular learning outcome "Ethical, environmental and professional responsibility" for students of different bachelor's degree programmes using gamification and simulation.

Debates

Cayzer (2010) talks about encouraging student debate as a way to discuss the role of sustainable IT in modern society. Casañ *et al.* (2020) present a 29-year history of the Social Impact and Professional Ethics of Informatics course at the Barcelona School of Informatics at UPC, which has students debate case studies about sustainable development in class and/or online. Alaswad and Junaid (2022) describe how they incorporate educational debates on sustainability and climate change in a course in the Mechanical Engineering programme at Aston University.

Challenge-based learning

Eldebo et al. (2022) and Norrman et al. (2022) cover the use of challenge-based learning in four courses in the Erasmus+ project *ScaleUp4Sustainability*, driven either by a provided external challenge or by aiming at one of the Sustainable Development Goals (SDG) or similar known societal challenges.

Case studies

Abernethy and Treu (2013) explain how they added a case study on sustainable development to an upper-level Project Management class, where several lectures and discussions were devoted to the issue of sustainability and its relationship to information technology (IT). Casañ *et al.* (2020) also discuss presenting case studies about sustainable development in class and/or online for student discussion. Gimenez-Carbo *et al.* (2021) also describe using case studies to motivate the development of the "Ethical, environmental and professional responsibility" cross-curricular learning outcome.

Seminars and lectures

Seminars and lectures are a very common pedagogical strategy which is also useful for education for sustainable development. Penzenstadler and Fleischmann (2010) incorporate sustainability into student discussions by starting with a master's seminar, later progressing to a student-led lecture series and finally establishing the topic in Teach-The-Teacher seminars and by integrating it into software engineering courses. Eriksson et al (2016) mention using lectures and seminars in three introductory sustainability classes.

Capstone projects

Cai (2010) has supervised several senior thesis projects on green computing. Palacin-Silva *et al.* (2017) describes four capstone projects developed by students from the Erasmus Mundus Master Course in Pervasive Computing and Communications for Sustainable Development (PERCCOM), showing how a sustainable development focus can be integrated into a traditional software engineering course.

Results for Research Question 3

Regarding the complexity level of the ESD learning experiences studied in this literature review, most of them are meant to be introductory experiences that incorporate sustainable development themes into computer-related engineering programmes. Also, the works reviewed do not state whether these are starting points for more advanced experiences in the curricula. A few of the articles found by this literature review belong to an intermediate or advanced level of studies. Cayzer (2010) talks about designing sustainability units for the Innovation and Technology Management Master of Science programme at Bath University, Penzenstadtler and Fleischmann (2010) discuss creating a master's seminar on sustainability, and Palacin-Silva *et al.* (2017) reports on capstone projects of a Master program focusing on sustainable development.

DISCUSSION

From our literature review, there is a widespread agreement on the importance of integrating sustainable development into all STEM programs (CDIO Standard 3). However, our work has shown a lack of consensus on guidelines for computer-related engineering curricula regarding either which core competencies (CDIO Standard 2) must be developed or how to update the curricula for effective competence development (Gamage *et al.*, 2022). For example, there is much discussion in the literature on which specific sustainable development topics make up the core curriculum, similarly to what is found by Faludi and Gilbert (2019), Pennington *et al.* (2020) and Martinez *et al.* (2021). Weiss *et al.* (2021) identify six distinct patterns for implementing education for sustainable development in higher education institutions, according to two distinct implementation phases: education for sustainable development can be implemented from the bottom-up, from the top-down, or both, and the impetus for change can come from within or from external stakeholders.

Gamage *et al.* (2022) state that the most appropriate pedagogical approaches for education for sustainable development problem/project-based learning, real-world or experiential learning, case studies and e-learning, as these are the most likely to effect change in individual behaviour toward sustainability goals by enhancing the domains of knowledge, skills and attitudes expected in ESD (CDIO Standard 7, 8). Our literature review reveals that most works discussed in the Research Question 2 review implement these pedagogical strategies. However, ESD requires systems thinking that considers foresight, long-term effects and the understanding of system interconnectedness, essential topics to address sustainability issues. As mentioned in Research Question 9993, most ESD experiences reviewed in this work are aimed at an introductory level and more advanced experiences are required in the curriculum to properly acquire mastery of SD competencies (Torre *et al.*, 2017; Gomes *et al.*, 2019; Chatterjee and Rao, 2020; Hansson *et al.*, 2022).

Our literature review also uncovered several barriers to the effective integration of sustainable development into computer-related engineering programmes. Among them, at the institutional and administrative levels, ESD requires support through resources, coordination, and appropriate incentives (Torre *et al.*, 2017). Long-term commitment to ESD must encompass not only a few study programmes that relate to the environment, but rather requires a campus-wide effort to change institutional cultures to ensure changes not only in program competencies but also in attitudes and behaviours toward sustainability at all levels.

Embracing sustainability may also challenge current teaching practices and require efforts to enhance faculty teaching competences (CDIO Standards 9 and 10). Finding motivated teachers that are competent in their own fields and knowledgeable about sustainability is a

difficult task. Faculty members must be prepared to work interdisciplinarily and transdisciplinarily with other faculty to tackle sustainable development themes, no easy task for computing-related programs, where IT's carbon footprint is mostly ignored, and reduction approaches are rarely worked upon with other engineering disciplines. Likewise, students should be prepared to work with other students from other programs and disciplines to address sustainability problems across disciplines in an efficient and orderly manner (Koniukhov and Osadcha, 2020). To that extent, faculty members must lead the way by setting an example. In our institution, since 2020, progress was made in aspects of disciplinary improvement (standard 9) and enhancement of faculty teaching competences by the issuance of 2 diplomas in innovation for university teaching (standard 10), but its effects in the teaching practices are still to be seen (Martínez-Araneda et al., 2022).

CONCLUSIONS

In this work, we present a literature review aimed at answering research questions regarding integrating sustainability into computer-related engineering programmes. Our results show that most curricular activities are still at the "Bolt-On" level: not fully integrated into courses nor into the curriculum. The literature discusses many examples of sustainable development being integrated into introductory courses of sustainability-oriented multidisciplinary courses, of latter-year capstone courses where students work on sustainable development projects and on senior theses on computational sustainability. Our findings from the collected data suggest that sustainability is under-represented in the computer science curricula. Furthermore, students would benefit from exposure to SD all through their study program and that there are many pedagogical strategies for this purpose which may be adopted depending on the course. Nevertheless, sustainable development is being promoted in the formal and informal curriculum.

At the pedagogical level, the literature on sustainable development education shows that, while some higher education institutions still favour traditional lecture-based courses, active learning methodologies are the prevailing trends. Among the works reviewed, we find many examples of problem/project-based learning, game-based learning, challenge-based learning, debates, case studies, capstone projects, and seminars and lectures being used. Our review also shows a lack of an SD experience track to achieve advanced competence levels and that there is no silver bullet to integrate SD into the curriculum.

The main contribution of this work is to serve as a guide in integrating sustainable development in a Computer Science program by defining program goals and learning outcomes related to environmental, social, and economic sustainability for our Computer Science curriculum reform process. Furthermore, this work can contribute to the selection of appropriate pedagogical approaches to sustainability teaching and learning.

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