Application of Sustainability Awareness Framework in Software Engineering Courses: Perspectives from ICT Students

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Abstract

The interest in sustainability has transcended beyond environmental studies to several disciplines, and ICT educators have been at the forefront of integrating the teaching of sustainability awareness and demonstrating practical competencies into computer science and software engineering curricula. However, empowering students in this field requires adequate hands-on to help them understand, adopt and consider the implementation of sustainable practices throughout the lifecycle of their developed solutions or tools. This paper describes the application of the Sustainability Awareness Framework (SusAF) in two Master level degree courses (1) Running a Software Project and (2) Requirement Engineering. We reported lessons learned and students' recommendations to improve SusAF as a sustainability awareness framework. Our findings reveal a promising step towards empowering future software engineers to build sustainable software systems and taking ownership of their role in achieving a sustainable society. The outcome of this application could help in teaching sustainability in other related courses and for further improvement.

Keywords

Sustainability, software engineering, software product, requirement engineering, SusAF, sustainability education

1. Introduction

In recent years, there has been an increasing interest in the concept of sustainability among scholars and practitioners because of the consequences of human activities on earth [1] and other external megatrends such as resource depletion, social inequalities, and cultural breakdown [2]. Furthermore, since sustainability encompasses various concerns such as environmental, social, individual, economic, and technical [3], building a sustainable future depends on communities and human resources that are aware of sustainability and the impact of human activity on the integrated environmental, economic and social aspects of sustainability [4]. However, despite the acknowledgment that companies recognize sustainability as a strategic priority [5], [6], a recent study shows that there is a lack of sustainability awareness and expertise in many ICT and software-related organizations [7]. As such, given that education is the bridge to sustainability [3] and today's students become future workforce professionals, creating sustainability awareness among students and exposing them to tools that build their competencies in solving real-life sustainability challenges becomes crucial.

Although sustainability education has increased recently among higher education institutions (HEI) [8], a survey of software engineers showed that many future engineering professionals in universities lack the expertise to start providing feasible solutions to society's wicked problems [9]. Thus, there is little sustainability awareness among software engineering students beyond the technical scope of systems learned in class [1]. Moreover, despite the existence of numerous fragmented sustainability

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frameworks and tools, there is little demonstration of how these frameworks could be introduced to software engineering students and get students' perspectives for improvement. As such, this paper seeks to find out the perception of software engineering students about sustainability and explore ways to broaden students' mindsets on sustainability issues. This paper seeks to answer two research questions: RQ1 What do software engineering students think about sustainability? RQ2 How can teachers create sustainability awareness and broaden students' sustainability mindset? To address these research questions, we introduced Sustainability Awareness Framework (SusAF) [10] to software engineering students in two different courses (Requirement Engineering Course and Running a Software Project Course).

SusAF is a question-based framework to raise awareness and identify the sustainability impacts of software systems on five dimensions of sustainability (social, individual, environmental, economic, and technical) across three levels of effects (direct, indirect, and systemic). We introduced SusAF to software engineering students and guided them to apply the framework in course projects to create sustainability awareness among these future software engineering professionals. The subsequent sections of the paper are arranged as follows: Section 2 discusses the background of the study. Section 3 describes how we executed the study. Section 4 presents the results. Discussion in Section 5 and concluding remarks in Section 6.

2. Background

Sustainable development definition, as widely cited, is a collection of activities that "meet the needs of the present without compromising the ability of future generations to meet their own needs" [11]. An undisputed understanding of the relevance of educational institutions in leading the awareness and training of topical sustainability issues is shared by many scholars [12]. As such, the significance of nurturing the next generation of sustainability champions and enthusiasts in the advancement of sustainability activities and actions cannot be over-emphasized. For example, LUT University, places a huge importance on empowering the students and society with sustainability skills and competencies to tackle many of the environmental issues. Furthermore, the university is well known for its leadership role in championing the implementation of sustainability courses and the integration of topical issues in many of its academic programs supported with the practical demonstration in its curriculum [13].

2.1. Sustainability awareness and ICT

Research studies have shown that STEM education plays a crucial role in promoting sustainable development and competencies. For example, Fronza et al. [14] and Wiek et al. [15] suggest several innovative approaches, such as project-based, inquiry-based, and interdisciplinary learning, to promote critical thinking, creativity, collaboration, and sustainability competency for STEM learners. In addition, we can foster partnerships between universities, businesses, and society by involving students in real-world sustainability projects and equipping them professionally for industry challenges. For example, Penzenstadler and Fleischmann [16] propose an integration of sustainability concepts into the HEI curriculum (especially software engineering) to foster a sustainability awareness mindset in the student before entering the industry. Similarly, Becker et al. [17] opined that there is an urgent need for an improved curriculum that has sustainability principles at its core to ensure the competencies and skills needed to engineer sustainable software are integrated into the learning curriculum.

ICT (software and systems) has been widely acknowledged as a contributor to sustainability challenges and a solution enabler to many of these sustainability issues [18]–[20]. Elliot [21] defined sustainable ICT as "the design, production, operation, and disposal of ICT and ICT-enabled products and services in a manner that is not harmful and may be positively beneficial to the environment during the course of its whole lifecyle." ICT's impact on the environment depends on rebound effects, which can offset its positive effects in the long term, resulting in uncertainty about its sustainability. The high productivity nature of ICT, its associated life cycle, and increasing environmental resources issues call for the attention of software engineering practitioners to be responsible for the sustainability of their products. And also the need for academia to accommodate sustainability into the university curriculum of software engineering, information systems, and computer science program [22]. By combining the technical dimension of sustainability with other dimensions, we may be able to evaluate and design the eco-friendliness of various ICT systems and solutions from their development stage to the end of their life cycles as they adapt to the dynamics of their operational environment.

2.2. Sustainability awareness and challenges in software engineering

As we have seen with ICT generally, the development and use of software systems have a considerable potential to bring positive environmental impacts through service optimization delivery, an overhaul of business processes, and lowering energy and resource requirements of the final digital products. However, there exists an inadequate understanding of how this can be embedded into the everyday activities of many organizations [23]. A similar dilemma applies to the software development process [24], [25], where awareness about potential software system effects is relatively low among many practitioners. Beyond acceptance of this challenge, software development practitioners must be empowered to take greater responsibility and ownership towards achieving sustainability of their products [10], [24]. A study by Becker et al. [17] highlighted the importance of requirements to influence software engineering practitioners to be responsible for the long-term consequences of the developed software products.

Several authors have characterized sustainable software in different ways. For example, Hilty et al. [26] viewed sustainable software as energy-efficient that, minimizes the environmental impact of the processes it supports and has a positive impact on social and/or economic sustainability, wherein such impacts are direct (energy), indirect (mitigated by service) or as rebound effects. Calero and Piattini [27] categorized sustainable software as one where the software code itself is being sustainable, agnostic of purpose, or the software purpose being to support sustainability goals. Sustainable software can also be characterized as the capacity of software systems to endure in certain ecosystems under current and future conditions with minimum negative environmental impact; empowering business growth and promoting good societal values [22], [28].

An industrial survey of software multi-sourcing vendors conducted by Salam and Khan [30] reveals eight critical risk factors to achieving sustainable software practice in the industry, including inadequate green RE practices, increased power consumption, resource requirements and CO_2 emission throughout the development process, inadequate software design guidelines, lack of coding standards and awareness of greener practices and lack of ICTs for coordination and communication respectively. For some companies, the challenge is that there is little understanding of how sustainability can be understood by software and requirements engineering professionals to facilitate sustainability design as an established part of the software development process [31], [32].

A related study on global software development by Khan et al. [33] highlighted the significance of sustainable software engineering by emphasizing the need to consider situational factor identification for each software engineering activity, including requirement engineering, modeling, construction, code reviews, and deployment in relations to dimensions of sustainable software engineering. Finally, Oyedeji et al. [25] summarized the sustainability challenges of software system design as the lack of readily available industry examples on applying the core principles of sustainability and best practices to influence developers' mindsets to adopt sustainability and translate it into their software development design decisions and practices.

The introduction of a sustainability awareness framework (SusAF) [10] provides researchers and practitioners with the needed tools and frameworks for raising awareness about the potential sustainability impact of software systems and products. The application of SusAF in the two-master level courses in this study aims to provide an understanding of sustainability in software systems to software engineering students and empower the students that will be future software engineering practitioners to consider sustainability effects and the impact of their design decision from all the sustainability dimensions.

3. Methodology

Survey research [34] was applied in this study to identify the awareness level of master students on sustainability and sustainability in software systems within two master degree courses (Running a Software Project course in Spring 2022 and Requirement Engineering Course in Fall 2022). The master degree students were given the same set of text form questionnaires at the beginning of each course (first lecture) and at the end of the course (after applying SusAF in the course project) to establish a baseline for comparison on the effectiveness of SusAF to promote sustainability awareness among master students. Figure 1 presents an overview of the research process in this study.

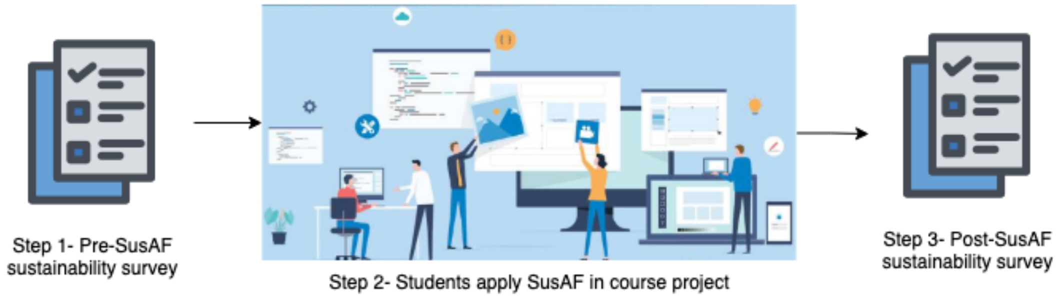

Figure 1: Study design and implement process

First, students were provided with pre-SusAF questionnaires before applying SusAF to identify student awareness levels on sustainability and sustainability in software systems. Next, students applied SusAF to their various software projects for sustainability impact assessments. Finally, students filled in a post-SusAF questionnaire at the end of the course, and the results were compared to the first results of the pre-SusAF questionnaire to check how well SusAF supported students' awareness of sustainability and sustainability in software systems. The post-SusAF questionnaires were also used to get feedback on what interested students the most about SusAF and their recommendations for improvement in SusAF.

3.1. Running a Software Project (RSP) Course in Spring 2022

This course is designed for students of the Software Engineers for Green Deal (SE4GD) [35] master program. The SE4GD master program is based on a strong software engineering foundation and a new perspective of combining sustainability with software development and an emphasis on societal effects. The course focuses on transforming customer requirements into sustainable software products and services. Students form teams that run a real software project from customer needs and requirements gatherring,to implementation and testing. Topics for the projects are generated by real customers (companies) based on sustainability themes.

Each team will create a project plan with proper requirements analysis, design, and implementation plan ending with real user testing. Finally, teams run their own projects independently, and the project is closed with a written report, a presentation of the project results, and a project postmortem analysis. Delivery of the solution to the customer is required to complete the course successfully. Below are the learning outcomes of the Running a Software Project Course:

1. Write a project plan for an actual software project
2. Identify the customer needs and turn them into software requirements for the project
3. Design a solution that fulfills most of the customer's needs
4. Carry out sustainability impact (environmental, social, economic, individual, and technical) assessment of design solutions and discuss with customers to agree on areas of improvement.
5. Implement the planned project in the given time
6. Test the implemented solution with real users in a real environment.
7. Present the results of the practical development project to the customers.
8. Have the ability to communicate efficiently within teams and with customers.

3.2. Requirement Engineering (RE) Course Fall 2022

This course is tailored for first-year master students to provide an understanding of the role of requirement engineering (RE) in software systems, products, services development, and enhancement. This RE course focuses on helping the student choose and apply requirements engineering (RE) techniques to different software development situations. The course considers various software development contexts, such as bespoke software development, market-driven, and agile development, and discusses how these contexts affect the choice of RE techniques. The RE course also provides students with the SusAF tool to assess sustainability impact during requirement engineering. The overall learning outcomes from this course are:

1. Perform requirements engineering in the context of the most common software development life cycles and processes
2. Develop effective functional and non-functional requirements that are complete, concise, correct, consistent, testable, and unambiguous.
3. Select the appropriate requirements elicitation techniques to identify requirements
4. Effectively analyze requirements and prioritize accordingly.
5. Create a requirements specification to communicate requirements to a broad set of stakeholders
6. Identify and discuss different sustainability impacts (environmental, social, economic, individual, and technical) with both technical and non-technical stakeholders.
7. Manage change to requirements

4. Results

This section presents the results of students' responses before and after using SusAF for sustainability impact assessment of software products and services in Running a Software Project Course Spring 2022 and Requirement Engineering Course Fall 2022.

4.1. Running a Software Project (RSP) Course - Spring 2022

This subsection details pre-SusAF and Post-SusAF survey results of the general sustainability understanding of students in the RSP courses. We highlight themes based on students' understanding of sustainability in software systems from pre-SusAF responses (Figure 2) and post-SusAF student responses in Figure 3. The themes with large fonts size represent the most frequent themes, while words in small font sizes represent the less frequent themes from the students' responses. As shown in Figure 2, Energy efficiency, saving energy, pollution reduction, efficient resource utilization, and software efficiency are the key themes in the word cloud (Figure 2). These key themes indicate that students of RSP course view sustainability in software systems mostly from the environmental and technical sustainability dimensions.

Figure 2: Pre-SusAF students' understanding of sustainability in software systems – RSP course

Similarly, the word cloud in Figure 3 presents the results of students' responses on what sustainability means in software systems after applying SusAF as a tool for sustainability impact assessment in their course project. Again, the emerging theme shows additional understanding reflected in their ability to relate to other dimensions of sustainability such as Individual (health, well-being, privacy); Social (Trust, Inclusiveness, Community); Technical (green code, architecture); economic (economic value); environment ($C0_2$ emissions).

Figure 3: Post-SusAF students' understanding of sustainability in software systems – RSP course

Table 1 details students' responses on what sustainability means to them prior to applying SusAF and after applying SusAF in the RSP course project. The pre-SusAF student perception of sustainability in Table 1 shows similar results to Figure 2 (students' perception of sustainability in software systems), in which students perceived sustainability majorly from environmental and technical dimensions. Additionally, the post-SusAF student perception in Table 1 reveals an improved awareness of the students' understanding of sustainability. Students could extend their sustainability concerns to other sustainability dimensions (individual, social, economic, technical, and environmental) compared to their responses before applying SusAF as shown in Table 1.

Table 1

Summary of RSP course student responses on their sustainability understanding

SN	Pre SusAF sustainability perception	Post SusAF sustainability perception
1	Meeting our needs without compromising the needs of future generations.	Sustainability is all about responsibility, ownership, and awareness of resource consumption.
2	Development, manufacturing, production, and consumption without harming the planet, people or depleting resources.	Taking responsible actions to make a positive impact on people, communities, and demonstrating sense of belonging to society.
3	Responsible actions to reduce CO_2 emissions and climate issues.	Sustaining/maintaining the quality of product/service without compromising the well-being of the environment and profit.
4	Effective and efficient resource utilization to protect the planet.	Sustainable work life balance with focus on people's mental health and societal welfare.
5	Creating prosperity without compromising the chances of future generations.	Prudent production and usage of resources while considering all sustainability dimensions.

Following the student's active and engaging application of SusAF in the RSP course, we summarize their recommendations for improvement in Table 2. These recommendations emphasized the importance of extending SusAF into a digital tool with guidance on data analysis and linking impacts to different stakeholders. Furthermore, SusAF should include guidelines on the right developmental actions to improve software system sustainability impacts after impact identification.

Table 2

Post-SusAF: Summary of RSP students' recommendation to improve SusAF

SN	Summary
1	Provide a digital tool to guide individual users and industry users in SusAF
2	Provide data analysis guidelines and capabilities without relying on instructor.
3	Automate the whole SusAF process to save time in analyzing the data.
4	Add one more layer on the visualization diagram: first circle for features, next three circles for 3 orders of impacts.
5	Digitally capture stakeholders' perspectives on SusAF. For example, in the analysis phase, each impact can be linked to stakeholders that are affected by it. It is difficult to show the stakeholders' perspective on the current SusAF diagram.
5	Provide guidelines on development actions after identifying impacts in SusAF.

4.2. Requirement Engineering (RE) Course Fall 2022

This subsection presents pre and post-application of SusAF survey results on requirement engineering students' understanding of sustainability in software systems and their perception of sustainability. Figure 4 shows the details network of keywords students used in their responses about sustainability in software systems prior to introducing them to SusAF. Figure 4 reveals that RE students' understanding of sustainability in software systems is limited to the technical sustainability dimension (e.g., green software) and environmental sustainability dimension (e.g., carbon emission and pollution).

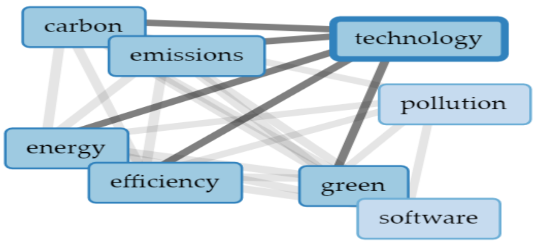

Figure 4: Pre-SusAF top keywords on sustainability in software systems from RE students

Furthermore, a post-application of the SusAF survey results among the same RE students at the end of the course shows a better understanding of sustainability in software systems, as detailed in Figure 5. This is evident in their description and linkage with all five dimensions of sustainability, which led to more keywords (see Figure 5) on sustainability issues that could impact software development activities and lifecycle in a broader way.

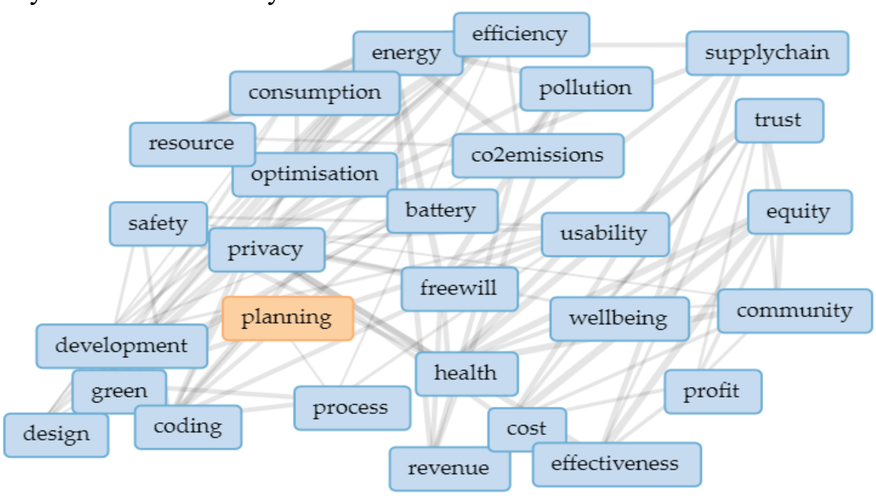

Figure 5: Post-SusAF top keywords on sustainability in software systems from RE students

The results presented in Table 3 summarize students of RE's perception of sustainability before and after SusAF was introduced to them. The results show that students' understanding of sustainability before using SusAF mainly centers on the environmental dimension focusing on factors such as the use of nuclear power, electric cars, reuse and recycling activities, and the technical dimension, focused on maintainable and reusable software. However, after the students were introduced to SusAF, the results indicate that SusAF helped improve RE students' general understanding of sustainability. The SusAF tool provided RE students with a broader view of sustainability, covering the individual, social, economic, technical, and environmental dimensions.

Table 3

Summary of RE students' perspective of sustainability before and after using SusAF

SN	Pre-SusAF sustainability perception	Post-SusAF sustainability perception
1	Less renewable energy like nuclear power.	Combination of the main five dimensions (individual, social, economic, environmental and technical) will enable a better future.
2	Move towards electric and hydrogen vehicles	Sustainability is about factors that affect the health of individuals and social interaction among groups of communities.
3	Effective use of environmental resources	Fulfillment of personal and collective needs without compromising the future ecosystem.
4	Companies and citizens to reduce carbon emissions.	Humans and companies can reduce C02 emissions by evaluating impacts of ativities.
5	Reuse things and do more recycling.	Sustainability means Inclusiveness, diversity, community building, equity.

At the end of the course, students from the RE course were tasked to critique the SusAF tool and recommend what they would like to improve in SusAF. As shown in Table 4, students emphasized the importance of including more detailed instructions to SusAF for easier understanding. Also, since the current version of SusAF is pdf and takes much time to complete the process from warm-up to reporting, students recommended having a digital software tool for SusAF to help improve the overall process of applying SusAF.

Table 4

Post-SusAF: Summary of RE students' recommendation to improve SusAF

SN	Response
1	Add instructions on the right dimension to start SusAF, a base point. For example, what is the right dimension to begin the process of SusAF for novice users of SusAF.
2	SusAF takes too much time to complete the process. Clustering should be done on entry to minimize work on the analysis part.
3	Transform SusAF into a web tool with interactive visual graphics and save paper waste from printing the pdf version.
4	The section about threats and opportunities looks redundant, but this is the essence of SusAF. Adding more explanation to this section and how it is linked to the chains of effects diagram should be made explicit. This will make SusAf users know that threats and opportunities cover both the negative and positive impacts, and actions are those features on what the developers can work on to improve the final impacts.
5	The framework should extend to Agile tools like Jira. For example, use the identified impacts in product road maps and scrum product backlog. In addition, the digital tool of SusAF should support tracking sustainability impacts identification and improvements of software systems. A guideline for companies on how to make this tracking will really improve the effectiveness of SusAF.

A significant finding from the post-application of SusAF survey results in the two courses Running Software Project and Requirement Engineering, as shown in Table 5, is the students' change of perception and increased interest to continue to use SusAF as a sustainability analysis tool in their other course projects. Overall, the student confirmed that SusAF is a good tool that empowers them to conduct thorough sustainability impacts assessment of software systems and a good starting point for students and practitioners interested in sustainability in software systems. While there is a need to digitize and improve the framework, the current features offer significant benefits, as summarized in Table 5.

Table 5

Summary of the most beneficial aspects of SusAF for RE and RSP Students

SN	Summary
1	SusAF provides a well-detailed understanding and thorough analysis of the software system's positive and negative impacts.
2	It provides an opportunity to view sustainability issues across multiple dimensions: environmental, economic, social, technical, and individual.
3	A framework to differentiate possible impacts of the software product and categorize them on a time scale of three "orders of impact" for easy analysis.
4	Provides insights to see the bigger picture of software products' sustainability impacts and how it could be useful for other software engineering courses
5	Comprehensive impact analysis for each dimension through their root cause (features) and excellent traceability across the three orders of impact.
6	A clearer way for individuals and organizations to visualize the sustainability impacts of the software systems and products.

5. Discussion

The results from the application of SusAF by students in running a software project and the requirement engineering course show an increase in students' sustainability awareness. The pre-SusAF survey results indicate that, students considered sustainability mainly from the environmental dimensions with a focus on resource utilization and C02 emissions compared to the post-SusAF survey results, which show students' views on sustainability broadened to include individual, social, economic, environmental, and technical dimensions of sustainability. This shows that SusAF can be a tool to support future software engineering professionals in solving some of society's wicked problems highlighted by Manotas et al. [9]. According to one of the requirements engineering students, "A*fter using SusAF for my team project, I have learned that sustainability is about more than environmental concerns. It also includes individual, social, economic, and technological aspects which affect our planet*."

Similarly, comparing the results of pre-SusAF and post-SusAF indicates an increase in student understanding of sustainability in software systems after using SusAF. Becker et al. [17] stated the importance of software engineering practitioners to be responsible for the impacts of the software systems they design and develop. The application of SusAF as a sustainability impacts assessment tool for software systems by students allowed students to gain in-depth knowledge on sustainability in software systems and recognize their role as key stakeholders in reducing the negative impacts of software systems. Through the use of SusAF, students could also recognize different factors in all the dimensions of sustainability that affect software systems sustainability. A statement by one of the students in running a software project course encapsulates this notion "*This course and the SusAF tool widened my perception of sustainability in software systems from the classic environmental point of* CO_2 *emission to things like users' health, privacy, inclusiveness, usability, economic value and sense of community.*" Results also in Table 5 indicate SusAF was a useful tool for students to assess software system sustainability impacts. For instance, one of the excerpts, as captured from the students, shows

SusAF "*provides an opportunity to view sustainability issues across multiple dimensions (environmental, economic, social, technical, and individual)*" This indicates a change in students' narrow view about sustainability prior to taking the two master courses. As such, software engineering educators have a bigger role to play in creating sustainability awareness among students through different teaching activities.

In addition, students' feedback on SusAF highlights the need to develop a digital tool to replace the current pdf version of SusAF to reduce the time spent conducting a SusAF workshop for software system sustainability impact assessment. The digital tool can also provide a better step-by-step guide to novice users on how to conduct a software sustainability impact assessment and analysis. The students' feedback also indicated the need to link identified sustainability impacts to different stakeholders. SusAF should also provide multiple stakeholder views of impacts that can be achieved through a SuAF digital software tool. Furthermore, students recommended linking SusAF to agile tools like Jira to support linking the identified sustainability impacts of software systems to the product roadmap and tracking during the development process in product and sprint backlog.

6. Conclusions

This paper shares insight into how a sustainability awareness framework was introduced to software engineering students in two different courses to create sustainability awareness among students and broaden their mindsets. Students' perception of sustainability was first assessed at the beginning of the courses and after they were introduced to the SusAF framework. Then, using a qualitative approach, our study explored two research questions, and the interesting findings are summarized below:

- RQ1: What do software engineering students think of regarding sustainability? The results showed that, at the start of the course, software engineering students had a myopic view of sustainability and limited sustainability to only environmental and technological issues.
- RQ2: How can teachers create sustainability awareness and broaden students' sustainability mindset? Evidence from the study showed that students in the two courses had a much broader understanding of sustainability after being introduced to SusAF. Students could also critique the framework and give feedback on what they liked about the framework and what could be done to improve SusAF usability, especially among students. A key part of the feedback was the need to get a web version of SusAF to replace the current pdf version. According to the students, this will save time and the environment for printing papers. Furthermore, there was a suggestion to link SusAF to Agile tools like Jira to support connecting identified sustainability impacts of software systems in the product roadmap and tracking during the development process. Overall, students appreciated that SusAF changed their perception of sustainability to include the five different dimensions and different orders of effects.

In conclusion, the purpose of HEI and educators can be summarized in two main points: (i) to educate future generations with both technical knowledge and professional skills to solve society's wicked problems; (ii) to broaden students' horizons and reinforce their values, morals, and principles in a complex society. In the context of this paper, software engineering teachers should therefore activate key competencies for sustainability courses to increase sustainability awareness among students in HEI. This could be achieved, for example, by using real-life industry scenarios, a practical reflection on sustainability issues, direct engagement of students with citizens to identify sustainability issues, sustainability-focused hackathons, and the application of relevant sustainability frameworks and models.

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