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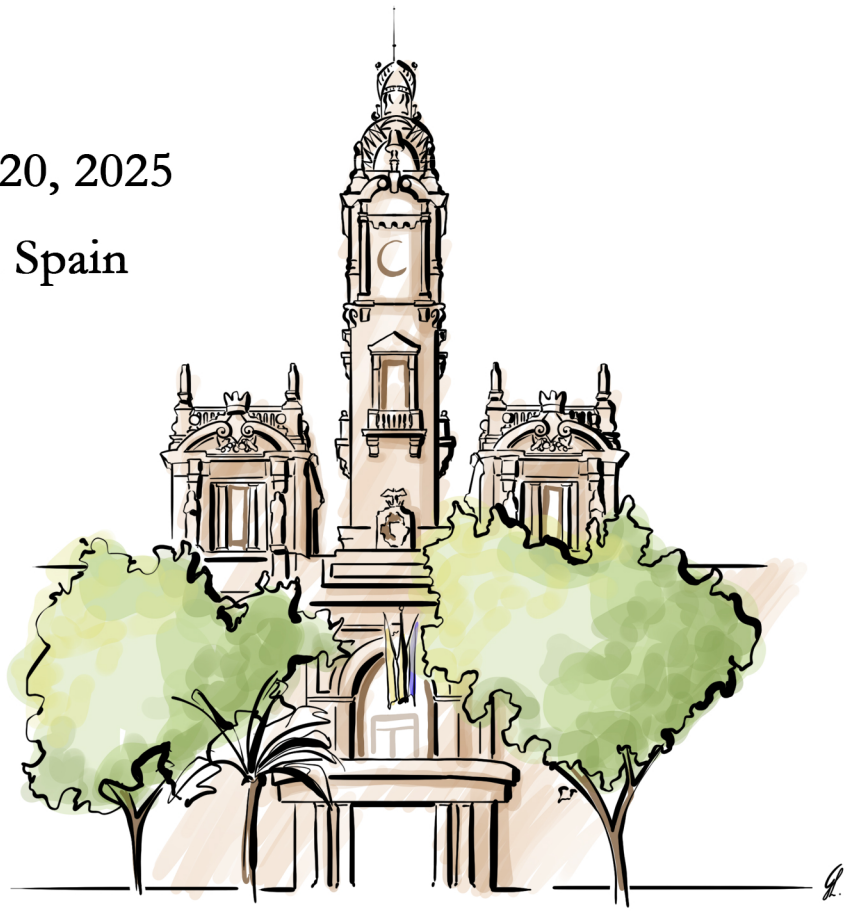

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TECSKILL: Development of a Green and Digital Competence Framework for Engineering PhD Students

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Abstract

The TECSKILL project (Erasmus+ KA220-HED) addresses the need to integrate sustainability and digital competences into the education of European Engineering PhD students. By adapting competences from the GreenComp and DigComp 2.2 frameworks, an integrated framework was developed, encompassing 12 sustainability and 21 digital competences. To monitor the learning progress, 137 knowledge indicators were defined across four proficiency levels, ensuring a structured assessment of skill acquisition.

The framework was implemented through four transnational training programs at universities in Spain, Italy, Portugal, and Sweden, providing PhD students with specialized lectures and hands-on workshops. A mid-term survey assessing student satisfaction confirmed the program's effectiveness in enhancing competences and fostering international collaboration. Future research activities will focus on evaluating competence acquisition over the whole project, assessing the impact of the trainings on students' research and professional development, and optimizing the developed competence framework based on the final outcomes.

Keywords: *Green competences, Digital competences, Engineering, PhD Students, Innovative teaching, competence assessment*

1. Introduction

The European Union is actively addressing the evolving challenges of digitalization and sustainability, prioritizing the adaptation and enhancement of its education systems to support

this transition (Reisoğlu & Çebi, 2020). To achieve this, structured competence frameworks have been established, incorporating descriptors reflecting relevant knowledge, skills, and abilities (Sánchez-Tarazaga, 2023). These frameworks are a valuable tool for defining effective educational strategies as they enable the creation of training programs aligned with the real needs of society. Specifically, the GreenComp (Bianchi et al., 2022) and DigComp 2.2 (Vuorikari et al., 2022) competence frameworks, developed by the Joint Research Centre of the European Commission provide a reference framework to support the development of training programs aimed at strengthening sustainability and digital competences. On the one hand, GreenComp falls within the actions of the European Green Deal (European Commission, 2019), identifying competences that form a structured learning framework for environmental sustainability. The framework consists of four core competence areas: "embodying sustainability values", "embracing complexity in sustainability", "envisioning sustainable futures" and "acting for sustainability". Moreover, each area encompasses three interrelated competences. Conversely, DigComp 2.2, aligns with the objectives of the Digital Education Action Plan 2021-2027 (European Commission, 2020), identifying critical digital competences and providing a standardized framework to support the digital transformation of European citizens. This framework consists of 21 specific digital competences, grouped into 5 areas: "problem-solving", "information and data literacy", "communication and collaboration", "digital content creation" and "safety".

In recent years, numerous studies have been conducted on different competence frameworks and their application in higher education (Mezinska et al., 2024). Rózewski et al. (2021) have compared the digital competence framework DigComp 2.1 with a competence framework developed through international projects for engineering education. Zhao et al. (2021) have conducted a literature review of current research on digital competence in higher education, concluding that most frameworks and strategies are heavily influenced by European Union policies and information. Additionally, in their study, Valor et al. (2020) have identified seven key competences for sustainable consumption that should be included in higher education curricula. Other authors, such as Lambrechts et al. (2013), have evaluated the integration of sustainability competences in two undergraduate programs, highlighting the importance of conducting appropriate analyses to correctly include the relevant competences.

Engineering is a sector in which digital and sustainable competences play a major role. Higher education programmes, particularly at doctoral level, must ensure a solid foundation and comprehensive training in these areas to provide future professionals and researchers in the field with the necessary skills. While the development of educational curricula on bachelors' and masters' levels has been focusing on sustainability and digitalization for several years now, also according to ACM/IEEE/AAAI guidelines (Servin and Becker, 2023), no precedent can be found on the implementation of such competence frameworks in engineering doctoral programs. To fill this gap, the TECSKILL project (Erasmus + KA220-HED) aims to develop a

comprehensive competence framework tailored to engineering PhD students to support and enhance their education and meet the needs of digitization and sustainability in Europe.

The paper is structured as follows. Section 2 presents the methods adopted to develop the competence framework in the context of the TECSKILL project. Moreover, it introduces the survey used to assess the satisfaction and opinions of the PhD students currently attending the training programs. Section 3 features the competence framework resulting from the combination of significant green and digital frameworks, as well as the feedback obtained through the survey. These preliminary opinions, as the training programs are still ongoing, are relevant to assess whether project objectives have been clearly communicated, the organization was adequate, and the learning activities were appropriately defined and executed. Finally, concluding remarks and future activities are presented in Section 4.

2. Methodology

2.1. Framework development

The development of the green and digital competence framework for Engineering PhD students involved researchers and professors from four European universities: University of Gävle (Sweden), University of Évora (Portugal), University of Parma (Italy) and University of Extremadura (Spain). First, to get an overview of key sustainability and digitalization goals, the participants evaluated the competences described in GreenComp and DigComp 2.2 frameworks. Then, these competences were adapted for Engineering PhD students following a three-phase approach: *i)* redefining the competence, *ii)* maintaining the scope of action, and *iii)* defining a new objective to be achieved after the acquisition of the competence.

Moreover, knowledge indicators reflecting the key skills to be acquired were defined for each competence. To track the learning outcomes and progress of the PhD students throughout the project, four levels were identified for each knowledge indicator, namely “A – basic”, “B – intermediate”, “C – advanced” and “D – expert”. For each knowledge indicator, the levels corresponded to indicative sets of skills that the student should possess. Finally, a panel of external experts was set up to determine the suitability of the developed competence framework.

2.2. First training programs and students’ survey

In the context of TECSKILL, the developed competence framework was adopted to design four transnational training programs. Each mobility consisted of ten days of lectures and workshops, where professors and researchers presented relevant and timely topics to the class, consisting of international PhD students, with a maximum of five participants for each university. The students came from different areas of industrial engineering: mechanical, management, chemical, mechatronics. To address this multidisciplinary audience and provide the main green

and digital skills identified, the lectures covered topics related to the following macro-areas, among others: *i)* applications of simulation and artificial intelligence for the monitoring, predictive maintenance and control of industrial plants; *ii)* concepts of automation, data acquisition and IoT; *iii)* project management and intellectual property; *iv)* sustainability, LCA, green logistics, material science and packaging. Students' progress was periodically tracked with the knowledge indicators. This allowed to directly assess the efficacy of the competence framework in supporting learning in higher education

After the third training program held in Parma (Italy) in January 2025, the doctoral students underwent a mid-term satisfaction survey. The survey consisted of 23 questions, designed to assess on a scale from 1 (completely disagree) to 4 (completely agree) the results of the training programs in terms of organization, clarity of communication of the project and teaching objectives, relevance of the activities for the research career, and general satisfaction with the training programs. As the project is still ongoing, should potentially problematic aspects emerge, student feedback could be used to make appropriate adjustments.

3. Results

3.1. Green and digital competence framework

The 12 competences proposed by the GreenComp framework were maintained and adapted for PhD students (Figure 1). For instance, the green competence "Promoting nature" aims to help students recognise that human beings are part of nature, encouraging them to respect the environment and all its inhabitants and restore ecosystems.

Competence	Goal
Valuing sustainability	Critical evaluation in terms of sustainability of values and actions during the engineering PhD student's research career
Supporting fairness	Be able to understand and extract all the scientific knowledge that improves the sustainability of society and implement it in current and future projects
Promoting nature	Evaluate the impact on the ecosystem of the different actions taken during the PhD student's research career and make decisions that are sustainable
Systems thinking	Understand the relationship between sustainability and the main variables of research projects and the interrelation of environmental variables
Critical thinking	Adquires a critical perspective that improves the capacity of PhD students, increasing their understanding and assessing of sustainability concepts
Problem framing	Identification of sustainability issues/challenges in engineering research and ability to define strategies to mitigate and resolve these challenges
Futures literacy	Be able to analyse the limitations and risks of future sustainable research strategies in order to be able to anticipate and establish lines of action
Adaptability	Knows that actions carried out during the research career can generate unpredictable situations that affect the environment
Exploratory thinking	Understand different perspectives to successfully address sustainable engineering research and explore new research methods
Political agency	Be able to understand and analyze political strategies that promote sustainability within their research career
Collective action	Develop skills that enable PhD students to drive sustainability through joint action and implementation of innovative solutions
Individual initiative	Empower individuals to confidently and consciously take sustainable initiatives in their lives, becoming agents of change and inspiring others

Figure 1. Green competences for Engineering PhD students.

Competence	Goal
Searching and Filtering information	Develop and implement an efficient and customized search strategy, incorporating information filtering, to identify the scientific literature
Evaluating information	Improve the ability to discern the validity and usefulness of digital resources in relation to research objectives
Information Management	To manage the information through innovative solutions that optimize the handling of digital data in research projects
Interacting through Digital Technologies	Use and critically integrate digital technologies in the communication of engineering research projects
Sharing through Digital Technologies	Develop skills and capacities to share digital content effectively through advanced technology. Promote transparency of research results
Engaging Citizenship	Effectively apply digital technologies to strengthen community interaction, address social challenges through research
Collaborating Through Digital Technologies	Dominate the strategic selection of digital technologies for knowledge co-creation and collaboration within engineering research
Behaviour through technologies	To develop skills in understanding norms of behaviour in the use of technologies and interaction in digital environments
Managing Digital Identity	Achieve a wider dissemination of the achievements and knowledge gained in your doctoral thesis through social networks
Development of digital multimedia content	Effective use of digital tools to achieve efficient communication of information generated during doctoral student research
Digital Content Integration	To develop the ability to rework scientific digital content for the creation of new scientific
Copyright and Intellectual Property Licensing	Develop the knowledge necessary to understand and effectively apply copyright and intellectual property licenses in research projects
Programming	Develop programming skills for effective process automation, analysis of experimental data and creation of customized computational tools
Protecting Devices	Critical evaluation in terms of security and adoption of risk prevention, eradication and/or mitigation measures in digital research environments
Personal Data and Privacy	Effective protection of privacy and personal data and privacy within research projects against potential digital risks and threats
Protecting Health and Well-Being	Development technical abilities in identifying and evaluating problems in the use of digital technologies and implementing solutions
Protecting the Environment	Ability to analyze how digital technologies used in research projects affect the environmental impact and establish methods to mitigate it
Troubleshooting technical problems	Be able to solve technical problems at different stages of the research project: preparation, simulation, experimentation and results
Identification of technological needs	Be able to identify technological needs in a research project and evaluate and implement appropriate responses to promote results
Creative use of digital technology	Be able to use digital technologies to support research by improving processes and creating knowledge to understand and solve problems
Identifying gaps in digital skills	Be able to identify gaps in the development of digital skills useful in my research work in order to improve them

Figure 2. Digital competences for Engineering PhD students.

This competence was adapted to engineering PhD students to encourage them to assess the impact on the ecosystem of the various actions taken during their research career, and lead them to make sustainable and environmentally-conscious decisions. Regarding the digital skills, the 21 digital competences of DigComp 2.2 framework were maintained and adapted (Figure 2).

To specify the necessary knowledge and skills for each competence, a total of 137 knowledge indicators were established. 89 of these indicators were related to digital competences, and 48 to the green ones. Taking green competence "Valuing sustainability" as an example, this has the knowledge indicators: "Understand the concepts and values of sustainability in engineering research", "Know how to align the values and objectives of a project with sustainability values", "Evaluate the sustainability of engineering research projects", "Analyze and select the best strategy or course of action to improve research sustainability". Within each knowledge indicator, four levels of progress were defined, with A being the basic level, B the intermediate

level, C the advanced level and D the expert level. Figure 3 shows the levels of progress of the previously mentioned indicator. All competences and indicators were reviewed by external experts, obtaining positive feedback on most of them. When needed, the appropriate corrections were made according to the experts' suggestions.

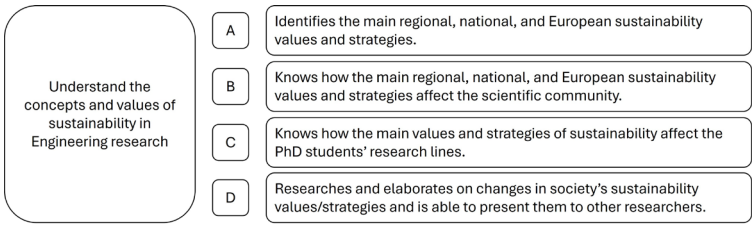

Figure 3. Levels of progress of a knowledge indicator of the "Valuing sustainability" competence.

3.2. Student satisfaction and opinions

The results of the students' survey, based on 15 answers, are shown in Figure 4. Overall, the feedback was very positive, a sign that the project was communicated effectively to the students. The training programs resulted effective in enhancing the students' green and digital skills, resulting relevant to the academic careers of the participants.

1.00	2.00	3.00	4.00

The objectives of the training programmes were clear and communicated effectively.	3.47
The activities of the training programmes were well-organized.	3.53
The project workshops and seminars were engaging and informative.	3.47
I found the content of the training sessions to be practical and applicable.	3.40
The training materials provided were comprehensive, helpful, and easily accessible.	3.40
The digital tools and platforms used during the project were easy to navigate.	3.47
Communication from the organizers was timely and clear.	3.73
Support was readily available whenever I encountered difficulties.	3.60
During the training programmes, the collaboration among participants was encouraged.	3.73
I gained valuable insights from interacting with other participants.	3.67
I appreciated the opportunity to visit different countries and explore their cultures.	4.00
I had the chance to bond and engage with other participants during extracurricular activities.	3.73
Thanks to the activities carried out during the training programmes, I can better evaluate sustainability issues in research.	3.27
I am now more aware of the environmental impacts of engineering research.	3.40
I now better understand how sustainability concepts can be integrated into practical solutions.	3.40
I am more skilled in using digital tools for data analysis and research.	3.27
I improved my ability to collaborate with others using digital technologies.	3.53
I gained a clearer understanding of my digital skill gaps and how to address them.	3.53
The activities carried out during the training programmes were relevant to my academic and professional goals.	3.13
The activities carried out during the training programmes encouraged me to reflect on the societal impact of my doctoral studies.	3.40
The training programmes I attended met my expectations.	3.20
Should other editions of TECSKILL Erasmus+ project be organised in the future, I would recommend other PhD students to attend.	3.80
I would participate in a similar project in the future if given the chance.	3.67

Figure 4. Results of the student satisfaction survey

Moreover, the programs were a valuable networking opportunity, and the participants recognized the value of collaborating with international peers. While all the evaluations were positive, rare cases (1 or 2 at most) of less positive evaluations were encountered, related to the relevance of the activities to the academic career, and the progress in green and digital skills. While such occurrences can be generally expected, this feedback will be considered during the design of the last training program in Gävle (Sweden).

4. Conclusions

This study describes the development process of a framework of green (12) and digital (21) competences adapted to the knowledge, skills and aptitudes that Engineering PhD students must acquire. Evidence from the literature shows how the definition of such competence frameworks is essential for the design of effective training and learning programs. 137 knowledge indicators were defined and will be used to monitor and track students' progress in developing the relevant skills and competences as learning activities unfold. To this end, for each knowledge indicator, a four-level progression was established to support the assessments.

International collaboration in the context of the TECSKILL project (Erasmus+ KA220-HED) has been fundamental in the analysis of existing competence frameworks developed by the European Commission and their adaptation for Engineering PhD students. The implementation of the developed framework during transnational training programs allowed for the international mobility of the participants. Based on the results of a satisfaction survey, this aspect was particularly appreciated by the students, as it gave them the possibility to collaborate, gain valuable insights from international colleagues, and even bond during extracurricular activities. Support and communication from the organizers were also highly appreciated by the participants. Overall, the PhD students were satisfied with having participated in the training programs and would suggest other students to take part in similar activities.

Future research related to the developed competence framework will focus on assessing the acquisition of green and digital competence during the whole project course. This evaluation will be possible after the end of the last training program in June 2025. The results of the first implementation of the developed competence framework will be essential in evaluating its effectiveness and in apporting eventual adjustments to the project goals and methods.

Acknowledgements

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