Manufacturing Science and Education 2025

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 68, Issue Special III, August, 2025

SAFETY IN ENGINEERING DESIGN: THE CRITICAL ROLE OF ERGONOMICS TRAINING IN INDUSTRY 4.0 CONTEXT

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Abstract: *Occupational safety issues represent one of the big challenges in Industry 4.0 context both for new technologies designers and companies that use new technologies to increase their performance. Considering user experience in engineering design is mandatory in the context of Society 5.0 that promotes human-centered design solutions. This paper aims to highlight the critical role of ergonomics training in safety-oriented engineering education, using a combined methodology based on autoethnography, narrative analysis and feedback received from participants in international pilot co-teaching sessions. The case study developed within an Erasmus+ cooperation partnership implemented in Spain, Finland and Romania, describes new learning and teaching methods tested in the context of Engineering Education 5.0 and presents participants' feedback related to ergonomics training experience.*
Keywords: *safety, user centered design, user experience, occupational risk, Engineering Education 5.0.*

1. INTRODUCTION

For many years human society has been facing an uncertain future and challenges due to the unsustainable use of resources. As a result, researchers are looking for solutions to incorporate sustainability issues in engineering projects, engineering education and new digital technologies development [1,2].

The integration of Industry 4.0 technologies introduces some significant occupational safety challenges for both technology developers and industrial adopters seeking to enhance their operational efficiency [3]. Concurrently, the concept of Society 5.0, emphasizing human centric design, necessitates the prioritization of user experience and needs within engineering design processes to mitigate these safety concerns [4]. Within this framework, engineers – as future developers of new technologies or future users of new technologies in industrial field – should be endowed with a mindset for sustainability, knowledge and skills for solving global changes, as Engineering Education 5.0 promotes [5].

In this context, the paper aims to present case study research based on the authors experience during the second round of implementing an international pilot co-teaching session with students in Engineering field in Spain. The article focuses on including aspects related to safety, ergonomics, user experience and user needs in training modules related to engineering design projects and provides insights into an educational process that sustains a sustainability-oriented mindset for participants.

As a main contribution, this article presents new learning and teaching methods tested in the context of pilot co-teaching sessions and suggests that ergonomics training is critical for implementing safety in engineering design.

The article is structured into seven sections. Following the introduction, the second section includes a bibliographic review and problem description and emphasizes the need for ergonomics in Industry 4.0 context. The third section describes the application field, highlighting the need for integrating safety and human centered issues in engineering design training, as Industry 5.0 promotes. The fourth part details the research stages and methods used and is followed by the results section. The last two parts of the paper are dedicated to results discussion, further research and conclusions.

2. PROBLEM DESCRIPTION

2.1 Occupational Safety Challenges and Ergonomics contribution in Industry 4.0

Technological advancement in Industry 4.0 introduces novel occupational hazards and occupational risks related to robots and digital technologies integration in organization. Social sustainability issues related to health and safety, well-being, hazard prevention and promotion of sustainable work represent a critical connection between Industry 4.0 implementation, the achievement of corporate social sustainability and sustainable development [2].

New legal responsibilities related to workers' safety and new safety-oriented challenges must be considered in managerial decisions [6]. One of these challenges is associated with ensuring workers' safety and well-being at work by identifying appropriate technological solutions, implementing safety-related measures and promoting a safety culture sustained by a proper safety-oriented education of workers. Under these circumstances, improving organization capacity to successfully implement new technologies systems and integrate them in organizations work processes [7] and the ergonomic design of working situations [8] become mandatory to respond to Industry 5.0 requirements for promoting safety and well-being integration in engineering design. Some of these ergonomics' interventions involve user-centric design of new technologies and the redesigning of working situations to reduce occupational risks and prevent musculoskeletal disorders, along with a safety-oriented education of new technologies users.

2.2 Problem statement

In this context, ergonomics training has become necessary for engineering students and safety-oriented education in companies, as well.

Engineering education programs need to support learners to develop a user-centered and safety-oriented mindset, by using modern teaching-learning methods and designing learning environments that sustain a proper understanding of ways of integrating different perspectives in engineering design – from user needs and experience, to financial, environment, health, safety and community needs.

3. ERGONOMICS TRAINING – A KEY FACTOR IN INDUSTRY 5.0 CONTEXT

One of the key aspects for ensuring the transition from Industry 4.0 to Industry 5.0 regards the continuous safety-related education of workers [3]. The evolving nature of work in Industry 4.0 is broadly discussed and includes new physical and cognitive demands on workers and changes in workers' roles, tasks and competencies.

Traditional ergonomics approaches to address these challenges are limited in contemporary work situations characterized by highly automated and interconnected work environments [2]. Thus, anticipating and preventing ergonomic risks become more important than just addressing them after they occur in a new work context.

In this context, empowering engineers with multidisciplinary skills for modern industry needs is mandatory [9] and safety engineering and management become a key topic in "industry of the future" education. This topic includes ergonomics alongside OHS, risk management and accidents prevention and management [10].

In Industry 5.0 context, human-centricity subjects like workplace ergonomics, human-centered design and human-machine interaction should be included in engineering education, especially in engineering and management specialization curriculum [10–12].

Developing tailored training sessions for recognizing specific ergonomic risks in new work context, qualifying engineers with human-centered design skills and empowering workers to be active participants in creating a safer work environment provide opportunities for safer integration of new technologies in organizations [13,14]. Therefore, ergonomics training as a proactive measure in Industry 5.0 context can produce organizational benefits such as: reduced injuries, improved productivity, enhanced quality and employee's engagement at work [2].

4. RESEARCH STAGES AND METHODS USED

The research presented in this paper is based on a case study developed within an Erasmus+ project and offers an example of developing and

testing the training content for an ergonomics training organized with the aim to foster students' awareness of different design perspectives, such as user needs and experience, ergonomics, safety, and the financial and social impact of engineering design solutions.

4.1 Research methodology

This article research methodology combines autoethnography, a qualitative method in the social sciences that explores the author's experience within cultural contexts [15], and feedback received from participants. The four stages of the research are presented in Figure 1.

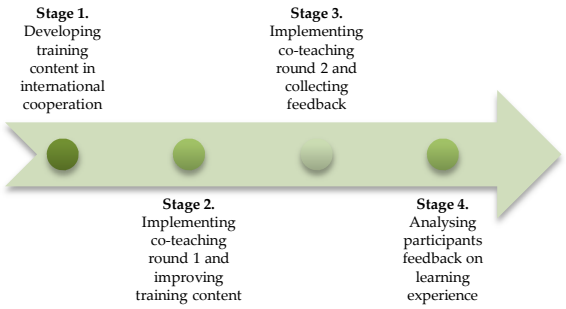

Fig. 1. Research stages

4.2 The educational process in co-teaching

NextGEng, an Erasmus+ funded international consortium with a duration of three years, aims to develop and implement innovative, student-centered pedagogical models for international co-teaching in engineering. The consortium was launched in October 2022 and comprises six partners: three higher education institutions (HEIs) – Technical University of Cluj-Napoca (TUCN), Jyväskylä University of Applied Sciences (JAMK), University of Jaen (UJA) – and three companies, one from each country [16]. International co-teaching teams integrating HEIs and industry specialists were formed to develop teaching modules for six designated courses. Design Projects was one of these courses, a course that exhibits curricular diversity, being titled Engineering Projects in Spain, Design and Ergonomics in Romania, and Ergonomics and User-Centered Design in Finland.

Following the first two stages of the research process, both internal analyses facilitated by international team video meetings and insights gained through participants feedback collected after Round 1, organized with students from all universities, led to the enhancement of the course educational content. Furthermore, the team decided to organize unified co-teaching sessions for Round 2, ensuring simultaneous participation and interaction among teachers from Finland, Romania, and Spain.

Different formats of joint teaching-learning sessions were planned and organized for the second round of co-teaching, as follows:

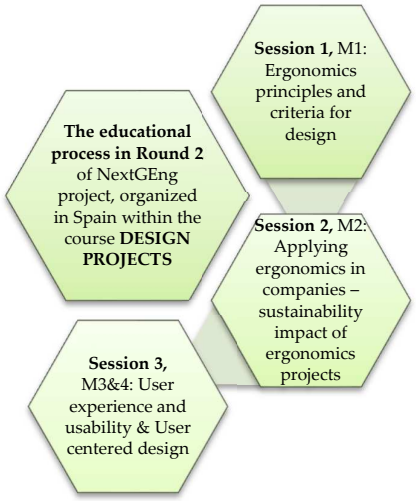

Fig. 2. An overview of the co-teaching sessions

- onsite co-teaching sessions in UJA (Spain), in two consecutive days
- online sessions in TUCN (Romania), one day
- hybrid sessions in JAMK (Finland), two days.

This paper focuses on the educational process implemented in October 2024 in UJA (Spain). The three consecutive co-teaching sessions were organized as Figure 2 shows and scheduled considering TUCN and JAMK invited teachers' mobility restrictions. Students in the 4th year from four different specializations get voluntarily involved within these sessions, as follows:

- Session 1, Module 1: Ergonomics principles and criteria for design (evening session, Electronics and Electrical Engineering). Using educational methods like question-based learning and videos, the students were introduced in ergonomics topic using a short movie presenting a tested device for cargo transportation. Issues related to work safety,

occupational risks, anthropometry and new technologies adoption risks were discussed.

- Session 2, Module 2: Applying ergonomics in companies, sustainability impact of ergonomics projects (morning session, all specializations). Using case study and students' presentations as educational methods, the students were grouped in teams that studied a short case related to an ergonomic-based and user-centered design project. The cases approached the following situations: (1) an ergonomic analysis of a repetitive work and related occupational risks – with the solution of workplace redesign and implementation of a completely new workplace design solution; (2) preventing musculoskeletal disorders at work using wearable devices like exoskeleton and safety training programs for employees; (3) designing for user needs, a case presenting an autonomous sea access device for people with mobility issues – with discussions related to user experience, usability and user-centered design, financial and social impact of engineering design solutions.
- Session 3, Modules 3 and 4: User centered design, user experience and usability (afternoon session, Mechanical Engineering and Business Engineering). Using examples-based learning and exposition, the session elaborated on user experience, usability and user-centered design topics.

At the end of all co-teaching sessions, feedback regarding the educational process was collected using the online Google Forms tool. All participants in all three sessions received the link to the questionnaire and more than 50% filled in the form and registered their opinion. Twenty answers were received and included in the qualitative analysis presented by this paper. The respondents' representation based on specializations is Mechanical Engineering (30%), Business Engineering (30%), Electrical Engineering (10%) and Electronics (30%).

5. RESULTS

This section includes students' statements and feedback on ergonomics co-teaching experience. The research results based on anonymous feedback provided by participants are presented in Figures 3–4 and Tables 1–5.

Participants feedback was collected using a questionnaire that included both closed questions based on 5-point appreciation scales "not very - very" / "poor - excellent" and open questions that allowed students to freely express their opinion on teaching-learning experience.

Four research variables were defined, in accordance with the questionnaire, as follows:

- V1 – overall satisfaction (How satisfied were you with the co-teaching sessions?)
- V2 – topic relevance (How relevant and helpful do you think it was for your future engineering projects?)
- V3 – co-teaching content (How would you appreciate the sessions content?)
- V4 – co-teaching methods (How would you appreciate the learning and teaching methods?).

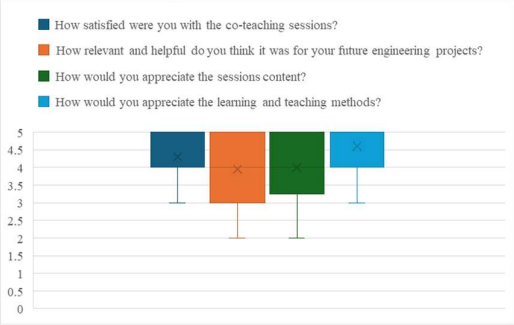

Fig. 3. Students' overall feedback on co-teaching.

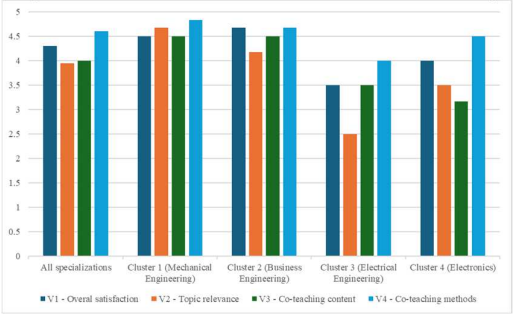

Fig. 4. Respondents feedback based on students' profile.

Table 1

Research variables' average score.

Students' specialization	Variables' average score			
	V1	V2	V3	V4
Cluster 1	4.5	4.67	4.5	4.83
Cluster 2	4.67	4.17	4.5	4.67
Cluster 3	3.5	2.5	3.5	4
Cluster 4	4	3.5	3.17	4.5
All specializations	4.3	3.95	4	4.6

The research results were analyzed using Excel and the average scores for defined variables were calculated both centralized and clustered by students' specialization.

Table 2

Students' feelings after co-teaching experience

Students' statements	Cluster
Motivated after learning new things that we are not used to hearing in subjects, and it is knowledge that causes an impact on the normal development of a lot of products.	Cluster 1 Mechanical Eng.
The sessions were very instructive, educational and interesting. It helped my friend and me to develop an idea for our final project.	
I felt good, the session was so interesting.	
I really loved it. We are learning new and modern concepts.	
The session was very interesting.	Cluster 2 Business Eng.
I am motivated and interested in the project.	
Grateful / Very successful / It's very interested	
After the session, I was motivated because I saw a different point of view, about a different topic, taught by teachers from other countries. It was one of my first experiences with international teachers.	Cluster 3 Electrical Eng.
I was interested in different kinds of design.	Cluster 4 Electronics
I feel that with the lectures, I can say that I now understand more about ergonomics and its many fields of application.	
Excited about international co-working	
I really felt good because I liked the experience	
I have been very interested in the subject.	

Table 3

Activities (learning methods) that students liked most in co-teaching sessions.

Activity (learning method)	Frequency
Group activity and students' presentations; "Presentation but I think that we should have more time to prepare it."	12
The teacher's explanations; Curiosities about past experiences of other companies	3
Slides with questions, talk in group; "The co-learning, when we helped the teacher with their development of the theme"	3
"The first day was very interactive, where we were looking for an ongoing conversation with the students, just like the second session, I like that because we are given the opportunity to express our opinion constantly and it is not a listening, listening, listening, and end. Although, the fact of studying a case and presenting it was somewhat more tense since the time and the non-habit of doing that type of teaching, caught me by surprise."	1

Table 4

The main takeaways from co-teaching sessions.

Students' statements	Cluster
The presentation forces you to understand everything and expose your thoughts. So learning is more direct.	Cluster 1 Mechanical Eng.
Ergonomics products and how to attend to all the difficulties of the people.	
The main things for me were ergonomic and usability concept and their applications.	
I am left with the examples that were given.	
Improve people's future.	Cluster 2 Business Eng.
We were able to see real cases in which the issue of ergonomics is present.	
The great importance of ergonomics in any aspect of any type of project.	
How important is ergonomics for the health of individuals, and how much we are neglecting it in universities or in companies. I don't think I will use this knowledge in an electrical project, but I can tell other engineers (Civil Engineers or Architects) to have ergonomics in consideration.	Cluster 3 Electrical Eng.
How important it is to travel to other countries to know their work methods.	
In general, rather than staying only with the concept of ergonomics, I am going to generalize more, and stay with the idea that an engineer, when designing, must consider and therefore think about everything. You should try to look at it from different points of view, to consider the engineer's view, the customer's view, financial, health, environment, etc.	Cluster 4 Electronics
Ergonomics is a must have when thinking in good design.	
It's impossible to make everyone happy when designing something.	
Value of the project, utility, durability	
Repercussions of small things in everyday life	
There is a list for human size.	

Table 5

Students' additional feedback

Students' statements	Cluster
I think it is a very positive experience, where professionals teach us new areas and ideas to take into consideration.	Cluster 1 Mechanical Eng.
I will keep doing these sessions for the future years. Maybe you can also introduce this concept of ergonomics in the project activity.	
I found the method of collaboration between teachers interesting, with the aim of giving students a greater level of understanding.	Cluster 2 Business Eng.
I find the topic of ergonomics very interesting, and I think the professors did a very good job in how they interacted with us and taught us so many real project cases.	

If the project continues, …I would continue trying to bring all the teachers at the same time to be able to carry out in three sessions almost in a row and so the issue is treated all at once, …I would put the attendance mandatory, since carrying out such interactive classes, the maximum number of people to discuss different ways is an advantage.	Cluster 4 Electronics

6. DISCUSSION

This paper presents an autoethnography-based case study related to the author's co-teaching experience within an Erasmus+ cooperation partnership, with students in four different engineering specializations in Spain.

In line with other international research, the results presented in the previous section show that respondents expressed positive feedback on the methods used in the co-teaching sessions.

For a deep analysis, a visual representation of students' overall feedback on teaching-learning experience, comparatively analyzed based on students' specialization, is presented in Figure 5.

The feedback received from participants revealed that respondents were satisfied (50%) and very satisfied (40%) with the co-teaching sessions. They considered the training very relevant (45%), relevant (25%), neutral (10%) or not relevant (20%) for their future engineering projects. This data is in accordance with some respondents' answers to open questions, as Tables 1 and 3 shows (e.g. a Mechanical Eng. student mentioned that the session inspired new idea for a final project; an Electrical Eng. student mentioned the awareness of ergonomics importance but also the doubt to apply it in future projects). Analyzing the results by clusters, based on students' specialization, it can be observed that Business Engineering (4.67) and Mechanical Engineering (4.5) respondents were very satisfied with co-teaching sessions.

Considering the respondents' perception on co-teaching topic relevance, the Mechanical Engineering (4.67) respondents appreciated the co-teaching sessions as very relevant and helpful for future engineering projects. However, the topic was perceived as least relevant and helpful (2.5) by the respondents from Electrical Engineering.

The findings of this article acknowledge the relevance of ergonomics-based training for the mechanical engineering field, considering that the curriculum of industrial engineering and management (business engineering) focuses on developing design competences related to human-machines interaction, user-experience and user-centered design [11] and in addition related to safety, health and wellbeing aspects.

Regarding the content of the co-teaching sessions, it was most appreciated by Business Engineering and Mechanical Engineering (4.5) respondents. Nevertheless, bearing in mind that many electrical engineers are involved in designing human-machine interfaces, control panels and other devices that people interact with, applying ergonomics principles in design ensure these interfaces are intuitive, safe, and comfortable to use, minimizing errors and user fatigue. While electrical safety is paramount for the electrical engineering field, physical safety and comfort also play an important role for future electrical engineers (e.g. proper lifting techniques for heavy equipment, comfortable working positions during installations, or well-designed personal protective equipment).

Respondents' appreciation on the teaching-learning methods used in co-teaching sessions, considering poor – excellent Likert scale, was excellent (65%) and very good (30%). Some respondents' feedback elaborated on the most liked educational methods, appreciating group activities and students' presentations (Table 3). In addition to that, the awareness of engineering design multiple perspectives and the importance of ergonomics for a good design solution were mentioned (Table 4). It can be highlighted that the educational methods used during the ergonomics-based co-teaching sessions were appreciated with an average score higher than four (very good) in all clusters.

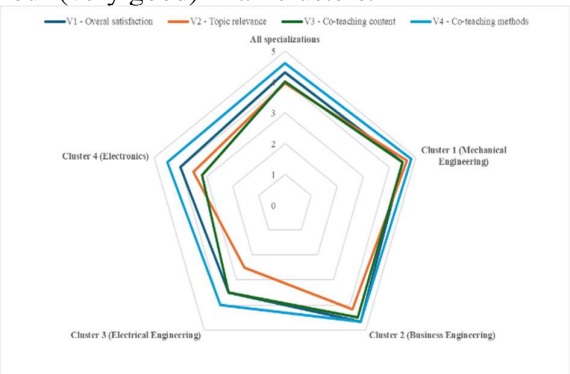

Fig. 5. Visual representation of research variables average score, comparatively analyzed by clusters.

In accordance with the conclusions of other research on the use of interactive educational methods [14], this article highlights the need for students' active involvement in the pedagogical process and their positive appreciation for a participatory teaching-learning process. Beyond that, some participants in the interdisciplinary co-teaching experience on ergonomics appreciated the internalization of both team-teachers and students, by involvement in Erasmus+ program.

7. CONCLUSIONS

The paper offers important arguments on the convergences between engineering education and practice, safety, ergonomics and Industry 4.0 evolution. The most important lesson learned through the case study developed within NextGEng project shows the importance of HEIs and company experts' collaboration.

The findings and the co-teaching experience presented in this article are expected to be used and extended by other pedagogical and research teams of experts in occupational safety, health and well-being, both national and international, HEIs–HEIs or HEIs–companies' teams, to respond to Industry 5.0 challenges brought by the new technologies design, development and adoption in organizations.

Furthermore, the training methods tested in the pilot co-teaching sessions with students can be extended to develop new educational content for HEIs curricula, for ergonomics and safety-related training sessions in companies and for lifelong learning education.

Firstly, the ergonomics-based training and teaching-learning methods presented in this paper can be used in safety-engineering curricula. For increasing sustainability-oriented mindset and awareness on safety and health-related topics, the following three principles can be applied: (1) using interactive pedagogical methods and active learning, (2) providing examples, scenarios and best practices for theory application in practice, and (3) encouraging participants' reflection, action and involvement.

Secondly, it is important to set proper pedagogical strategies that reflect at least the following four aspects: (1) defining students-centered learning goals focused on competence improvement, considering both quality and quantity, (2) designing learning environments for stimulating active participation, (3) assessing periodically the teaching-learning process, to identify areas for growth and learning experience improvement, and (4) developing teachers' resilience and mindset for experiencing new and different pedagogical approaches.

This study concludes by emphasizing the necessity of integrating ergonomics training into safety-engineering curricula. To ensure resilience within the framework of Industry 4.0, it is imperative that both HEIs and companies operating in the industrial field adopt proactive strategies that go beyond compliance with OHS regulations, developing competencies in human-centered design, potentially even through short modules integrated into traditional OHS courses.

8. ACKNOWLEDGEMENT

This work has been developed within the framework of NextGEng project (International Cooperation Framework for Next Generation Engineering Students) – grant number 2022-1-RO01-KA220-HED-000088365, coordinated by Ciprian Lăpușan, Technical University of Cluj-Napoca, Romania.

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Siguranța în proiectarea inginerească: rolul critic al instruirii în ergonomie în contextul Industriei 4.0

Problemele de securitate ocupațională reprezintă una dintre marile provocări în contextul Industriei 4.0 atât pentru proiectanții de noi tehnologii, cât și pentru companiile care folosesc noile tehnologii pentru a-și crește performanța. În contextul Societății 5.0 care promovează soluții de proiectare centrate pe om, luarea în considerare a experienței utilizatorului este obligatorie în proiectarea inginerească. Această lucrare își propune să evidențieze rolul critic al formării în ergonomie în educația inginerească orientată spre siguranță, folosind o metodologie combinată bazată pe autoetnografie, analiză narativă și feedback primit din partea participanților într-o sesiune pilot de co-predare internațională. Studiul de caz dezvoltat în cadrul unui parteneriat de cooperare Erasmus+ implementat în Spania, Finlanda și România descrie noi metode de învățare și predare testate în contextul Educației în inginerie 5.0 și prezintă feedback-ul participanților legat de experiența de formare în ergonomie.

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