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The “Eagle” Approach To Train Electrical Engineers With Collaborative Problem-Solving Skills

Fereshteh POORMOHAMMADI
ELECTA, ESAT, KU Leuven, Belgium, fereshteh.poormohammadi@innoenergy.com

Merijn VAN DEYCK
ELECTA, ESAT, KU Leuven, Belgium, merijn.vandeyck@kuleuven.be

Martijn DECKERS
ELECTA, ESAT, KU Leuven, Belgium, martijn.deckers@kuleuven.be

See next page for additional authors

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Authors

Fereshteh POORMOHAMMADI, Merijn VAN DEYCK, Martijn DECKERS, Abdul SABOOR, Bowen WANG, Pouya MEHRJOUSERESHT, Zhenda ZHANG, Arne SYMONS, Pieter PAS, Alexander BODARD, Hans VAN ROOIJ, Marian VERHELST, Alexander BERTRAND, Ruth VAZQUEZ SABARIEGO, Panagiotis PATRINOS, and Peter COPPENS

THE "EAGLE" APPROACH TO TRAIN ELECTRICAL ENGINEERS WITH COLLABORATIVE PROBLEM-SOLVING SKILLS

F. Poormohammadi [1]
Department of Electrical Engineering-ELECTA, KU Leuven
Leuven, Belgium
0000-0002-6300-0089

M. Van Deyck
Department of Electrical Engineering-ELECTA, KU Leuven
Leuven, Belgium
0000-0002-0162-8997

M. Deckers
Department of Electrical Engineering-ELECTA, KU Leuven
Leuven, Belgium
0000-0001-9652-7189

A. Saboor
Department of Electrical Engineering-WaveCore, KU Leuven
Leuven, Belgium
0000-0002-6512-1562

B. Wang
Department of Electrical Engineering-MICAS, KU Leuven
Leuven, Belgium
0000-0003-4946-8432

P. Mehrjouseresht
Department of Electrical Engineering-WaverCore, KU Leuven
Leuven, Belgium
0000-0003-4248-1095

Z. Zhang
Department of Electrical Engineering- IMEC-COSIC, KU Leuven
Leuven, Belgium
0000-0002-6508-0350

A. Symons
Department of Electrical Engineering-MICAS, KU Leuven
Leuven, Belgium
0000-0002-4595-9384

P. Pas
Department of Electrical Engineering- STADIUS, KU Leuven
Leuven, Belgium
0000-0002-7004-2447

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[1] *Corresponding Author: F Poormohammadi*

Fereshteh.poormohammadi@kuleuven.be

A. Bodard
Department of Electrical Engineering- STADIUS, KU Leuven
Leuven, Belgium
0000-0001-7558-8249

H. Van Rooij
Department of Electrical Engineering- STADIUS, KU Leuven
Leuven, Belgium

M. Verhelst
Department of Electrical Engineering- MICAS, KU Leuven
Leuven, Belgium
0000-0003-3495-9263

A. Bertrand
Department of Electrical Engineering- STADIUS, KU Leuven
Leuven, Belgium
0000-0002-4827-8568

R. Sabariego
Department of Electrical Engineering- ELECTA, KU Leuven
Leuven, Belgium
0000-0001-7515-3923

P. Patrinos
Department of Electrical Engineering- STADIUS, KU Leuven
Leuven, Belgium
0000-0003-4824-7697

P. Coppens
Department of Electrical Engineering- STADIUS, KU Leuven
Leuven, Belgium
0000-0002-0224-2447

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ABSTRACT

Engineering education plays a critical role in addressing the ever-increasing environmental and societal challenges, and collaborative problem solving (CPS) is a vital skill for engineers to tackle such complex multidisciplinary challenges and develop high-quality solutions. The EAGLE project at KU Leuven exemplifies CPS implementation in electrical engineering education, providing students with real-world connections and deep learning opportunities to develop teamwork, problem-solving, and negotiation skills.

This paper presents the development and implementation of EAGLE, a year-long hands-on, multidisciplinary challenge in which teams of 10-12 students design and develop an autonomous drone capable of flying to a remote landing station. It focuses on the project organization, innovative coach-based teaching and grading system, and the multi-dimensional evaluation and grading processes employed.

The insights gained from the EAGLE project can offer valuable lessons for future project-based learning initiatives and encourage the adoption of innovative teaching and learning approaches in engineering education. By sharing our experiences, we aim to inspire other educators to integrate real-world projects into their curricula, emphasizing the significance of hands-on learning, teamwork, and CPS in engineering education.

1 INTRODUCTION

Engineers are trained to become creative problem solvers, capable of applying knowledge in many domains, including mathematics, physics and computer science, to tackle complex multidisciplinary problems. Collaborative problem solving (CPS) is indeed an essential 21st century skill for stimulating creativity, and high-quality solutions, relying on ideas, experiences and information from multiple perspectives (OECD 2017). CPS entails the collaboration of two or more students to come to a unified solution for a problem by sharing and integrating ideas, skills and knowledge. It challenges both technical knowledge and social skills of students, preparing them for practical work environments where problem-solving is a collective effort rather than an individual one (Sun et al. 2020; Andrews-Todd and Forsyth 2020). Deep learning opportunities provided by CPS allow students not only to increase their conceptual understanding and content-related knowledge but also to develop these necessary social skills. In accordance with the self-determination theory, by working collaboratively towards a common goal, individuals are motivated to achieve higher levels of performance and engagement, leading to more efficient and effective problem-solving outcomes (Deci and Ryan 2000). Therefore, understanding the concept of CPS and its underlying motivation is crucial for educational and practical settings (Deci and Ryan 2000; Raes, Pieters, and Vens 2022).

The EAGLE project at KU Leuven serves as a notable example of implementing the CPS concept in Engineering education. However, it is important to note that the presence and extent of CPS tasks can vary across different engineering programs, contexts, and countries. As a result, students enrolled in certain programs or situated in specific regions may have limited opportunities to engage with CPS tasks during the initial two years of their undergraduate education. Nevertheless, within the context of engineering bachelor's programs at KU Leuven, students encounter instances of Collaborative Problem-Solving (CPS) tasks at different stages. These tasks involve applying engineering skills to develop solutions for multifaceted multidisciplinary problems. The EAGLE project, which takes place in the third year, represents the culmination of this process. It not only establishes a tangible link to society by addressing the demand for unmanned aerial systems in diverse applications but also provides students with a comprehensive and challenging multidisciplinary task. Throughout an entire academic year, students work collaboratively in teams of 10-12, showcasing their ability to solve complex problems together.

The autonomous drone project involves various domains, mainly mechanical, electrical, and software engineering. It provides valuable learning experience while assessing students' competencies through transparent scoring approaches, peer feedback, and effective guidance by a large team of teaching assistants (TAs). It is worth mentioning this project is part of the curriculum of approximately 80 students, guided by roughly 20 TAs and 9 professors.

This paper presents the employed strategy in the "EAGLE" project to promote collaborative problem-solving in engineering education. We explore the challenges that arise in such an approach and highlight the solutions, including efficient and effective guidance, and multi-dimensional evaluation. By sharing our experience, we hope to inspire other educators to incorporate real-world projects in their curriculum that provide students with valuable skills and knowledge.

2 METHODOLOGY

In this section, we will first discuss the project description given to the students, followed by how the project is supervised and finally how it is graded.

2.1 Project Description

Unmanned aerial vehicles (UAVs), commonly known as drones, have experienced significant advancements in terms of affordability and technology. These advancements have facilitated the integration of various sensors, wireless communication capabilities, and intelligent autonomous systems, thereby unlocking a wide range of innovative applications, such as maintenance inspections of infrastructure, optimizing energy management through smart meter data, and delivering essential supplies to remote or inaccessible locations, including vital medications. The widespread utilization of these smart drones, however, requires seamless integration of diverse electronic components, enabling efficient operation.

The EAGLE project at KU Leuven attracts students primarily enrolled in the electrical engineering bachelor's program. While the exact demographics of the student cohort can vary from year to year, the project involves approximately 80 students (and maximum 120 students) who collaborate in self-organized teams of 10-12. The students have the freedom to choose their team members, and there is no specific requirement for diverse backgrounds, although it is often beneficial. Students are encouraged to complement their skills by collaborating with peers who have different expertise. The TAs/coaches assist in the splitting of modules, providing guidance on workload distribution and the skills required for each module. However, the final decision on task allocation within the teams lies with the students, allowing them to take ownership of their work and make choices based on their interests and strengths.

The primary objective of the project is to develop an autonomous drone capable of navigating towards a predetermined destination, where it will provide wireless power to illuminate an LED wall. Since the precise location of the LED wall is initially unknown, the drone must navigate along a designated path marked by a series of

QR codes arranged in a regular grid pattern, represented by red lines. Along this path, the drone will encounter and overcome various challenges, such as operating under remote control, executing autonomous loitering maneuvers, and ultimately achieving full autonomous flight. A graphical representation of this mission is provided in *Fig. 1*.

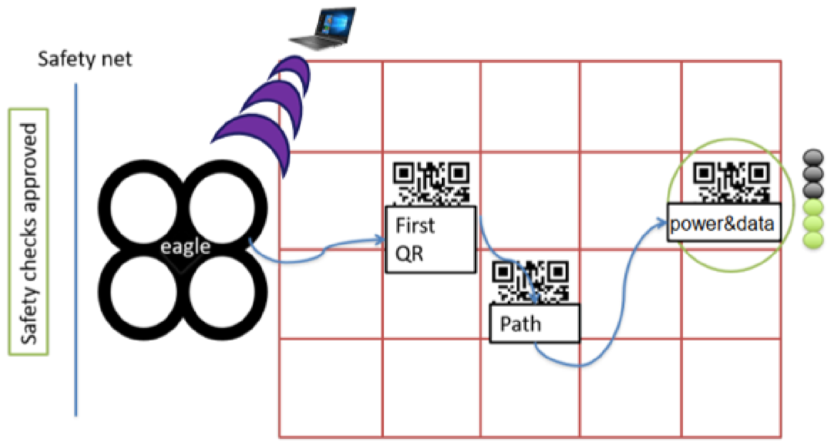

Fig. 1. Graphical representation of the EAGLE mission

The EAGLE mission is divided into multiple submodules, all of which contribute to its successful realization. These submodules are carefully designed to address specific aspects of the project and foster collaborative problem-solving among the student teams. By dividing the project into distinct modules, students are able to focus on key areas of expertise while also working collectively to integrate their solutions into a cohesive and functional drone system. In the following, we explore each of these submodules in detail to understand the tasks assigned to the students and the collaborative problem-solving skills they develop along the way:

(1) Autonomous Navigation Controller (ANC): Students are responsible for developing the flight control module of the drone, which involves hierarchical controller design and software implementation. The controllers stabilize the drone's attitude, altitude, and navigation along the QR trail. This submodule allows students to showcase their collaborative problem-solving skills in achieving stable and precise drone flight using software deployed on an embedded platform.

(2) Image Processing (IMP): In this submodule, students focus on the vision system of the drone. They utilize the camera feed to determine the drone's position based on the red line grid and detect and parse QR codes to identify the next flight target. Through this task, students have the opportunity to demonstrate their collaborative problem-solving abilities in developing the drone's vision capabilities using image processing techniques.

(3) Simultaneous Wireless Information and Power Transfer (SWIPT): Students tackle the implementation of hardware and embedded software for inductively transferring power from the drone's battery to a remote LED wall. They also leverage the power transfer link to transmit mission data and inductive link efficiency to an external LCD screen. This submodule emphasizes the students' collaborative problem-solving skills in developing efficient power transfer mechanisms and optimizing the communication between the drone and external devices.

(4) Communications (COMMS): Students develop a command center framework within the EAGLE drone to enable communication between different modules and a remote base station. They create a web Graphical User Interface (GUI) that displays crucial drone parameters, such as live video feed, drone coordinates, and telemetry data, and allows parameter upload capabilities. This submodule showcases the students' ability to collaboratively solve problems in optimizing wired and wireless routing and ensuring seamless communication within the drone system.

(5) Cryptography (CRYPT): In this submodule, students analyze the QR codes encountered along the drone's path. They authenticate the QR codes to ensure they are not malicious and decrypt them to obtain target coordinates. Students implement authenticated decryption algorithms in software and hardware, utilizing the FPGA on the Zybo board to accelerate real-time operations. This task highlights the students' collaborative problem-solving skills in ensuring data security and integrating cryptographic functionalities into the drone system.

2.2 EAGLE Timeline and Milestones

The EAGLE project comprises a well-structured timeline and milestone framework that not only enables students to develop the necessary technical skills but also emphasizes the cultivation of collaborative problem-solving abilities. Spanning across two semesters and consisting of a series of sessions (a total of 75 sessions, each lasting 2.5 hours), students engage in hands-on learning experiences to accomplish their EAGLE mission while honing their soft and technical skills.

The project timeline consists of four evaluation moments (T1-T4), shown in *Fig. 2.*, each with corresponding milestones for each module. These milestones provide students with clear targets and foster their problem-solving abilities. After each evaluation, students receive extensive feedback, facilitating continuous improvement and learning.

[T0-T1]: The project begins with the **"Understand & Plan"** phase, emphasizing collaborative teamwork and effective communication. Students engage with their coaches (see next section) to comprehend the project's scope, allocate tasks, and establish well-defined interfaces. The team must also assign specific roles to each member to ensure effective collaboration throughout the project.

[T1-T2]: Moving into the **"Modeling"** phase, students work on their respective modules, aiming to achieve technical milestones demonstrated during demo and poster sessions. This phase encourages students to develop virtual component models and create initial versions of the project's modules, honing their problem-solving and modeling skills.

[T2-T3]: During the **"Component"** phase, students focus on module implementation, aiming for independent functionality by the second demo and poster session. Integration of modules begins, leading to a second set of milestones. This phase nurtures their ability to solve complex problems while collaborating on system integration.

[T3-T4]: The final **"Integration"** phase brings all modules together, gradually transforming the drone into an autonomous entity. This phase showcases students' problem-solving skills in integrating diverse components into a cohesive system. The project concludes with a final demonstration and presentation, further enhancing their collaborative problem-solving and communication abilities.

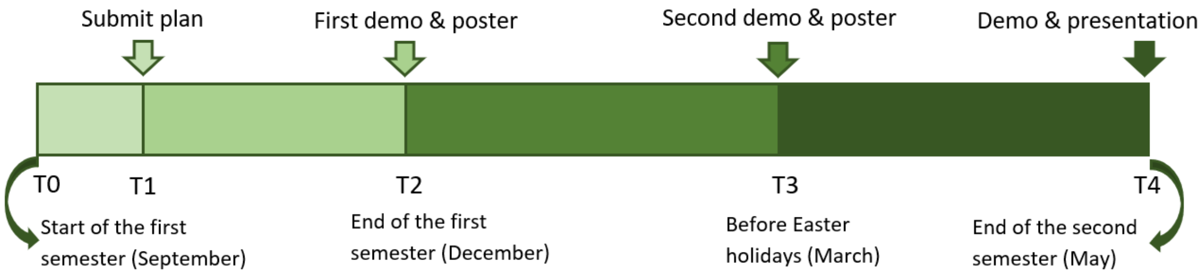

Fig. 2. EAGLE timeline and four evaluation moments

In addition to technical milestones, students are expected to develop and demonstrate soft skills throughout the project. Reporting on progress, reflecting on problem-solving approaches, and presenting technical solutions through various mediums (such as blogs, poster presentations, and live demos) foster effective communication, planning, and reporting skills essential for their future professional careers.

2.3 Teaching

The EAGLE project presents students with two distinct challenges that they must address simultaneously. Firstly, they are tasked with tackling a technically complex problem, requiring them to apply their knowledge and skills to overcome various technical challenges. Secondly, students must navigate the organizational complexities that arise from working in large groups, including effective teamwork, communication, and coordination. Moreover, the project emphasizes on fostering problem-solving capabilities within a collaborative team environment while also encouraging individual independence. By promoting both teamwork and individual autonomy, the EAGLE project aims to develop well-rounded and capable students.

To support students in their journey, the EAGLE project provides them with the autonomy to plan their work, manage their team, and establish effective communication tools. However, it is most likely that at certain stages of the project, students may require assistance or guidance. To ensure adequate support, the EAGLE students are accompanied by a dedicated team of professors and teaching assistants (TAs).

The support primarily refers to supporting each group of students collectively. The teaching staff meets with the group as a whole during the two designated days per week when students actively work on the project. These meetings serve as an opportunity to provide guidance, monitor progress, and address any group-level challenges or concerns. Additionally, the teaching staff recognizes the importance of individual support within each group. Students are encouraged to reach out to the teaching staff individually via email or through a dedicated program and web interface when they encounter specific problems or require personalized guidance. Furthermore, in the event of any issues or conflicts arising within a group, the teaching staff engages in one-on-one meetings with each member of the group. This approach allows for a more personalized and targeted resolution of problems, ensuring that the needs and concerns of each student are adequately addressed. The task division within the team of teaching staff is as follows:

Coaches: Two coaches, consisting of a Teaching Assistant (TA) and a supervisory professor, are designated to each EAGLE team of 10-12 students. The coaches are responsible for guiding and supporting the EAGLE team to foster effective teamwork and collaboration and emphasizing the development of soft skills across five key dimensions:

(1) Interpersonal Skills: Coaches assist team members in effective collaboration within a diverse, multi-disciplinary group.
(2) Problem Solving: Coaches encourage a balance between independent problem-solving and seeking help when needed, fostering creative techniques.
(3) Motivation: Coaches motivate teams to strive for higher goals and exhibit commitment towards their objectives.
(4) Project Planning: Coaches help teams devise comprehensive short-term and long-term plans, adapt and modify their plans based on their progress, ensuring timely and flexible adjustments.
(5) Project Management: Coaches emphasize regular meetings with structured agendas to synchronize progress, address challenges, and ensure well-organized project development.

Initially, the coaching approach is intensive, with active guidance and clear communication through in-person or online meetings. As the team progresses, the coaching transitions to a high-level supervision role, allowing the team to take on more responsibility for their work.

Overall, the coaches facilitate team growth by creating a collaborative environment and gradually empowering the students to work autonomously.

Technical experts: As already explained, the project is broken down into smaller modules, namely ANC, IMP, SWIPT, COMMS, and CRYPT. There are at least 2 technical experts for each of these modules. Their expertise helps students tackle complex technical challenges and ensures smooth progress throughout the project. Here are the key responsibilities and expectations for technical experts:

(1) Documentation Support: Technical experts are responsible for ensuring that students have access to proper documentation related to their respective modules. This includes providing relevant resources, reference materials, and technical guidelines to assist the teams in their work.
(2) Availability for Assistance: Technical experts are expected to be available to answer questions and provide guidance to the students. Promptly responding

to inquiries via email or other communication channels is essential in helping teams overcome technical issues they may encounter.

(3) Weekly Team Check-ins: Technical experts are required to check in with each team on a weekly basis. This allows them to monitor the teams' progress, provide feedback, and address any technical issues they may be facing. Regular engagement with the teams helps maintain a collaborative and supportive environment.

(4) Foster Effective Problem-Solving: Beyond technical skills, technical experts involve teaching students how to ask the right questions and directing them to the appropriate resources for finding answers. Encouraging creativity and innovative thinking while cautioning against unnecessary complexity helps the teams approach problem-solving in an efficient and effective manner.

Behind the scenes, the teaching staff meet regularly (at least bi-weekly) to discuss the progress of each team and address potential bottlenecks, such as hardware, software, and organizational issues. This collaborative effort allows the staff to provide guidance while empowering the students to take ownership of their work. To ensure the smooth knowledge transition to new Teaching Assistants (TAs), they receive training by shadowing senior TAs before assuming full responsibilities. Additionally, senior TAs organize a training day for the entire teaching staff prior to the start of the academic year. This training session focuses on tackling key project challenges, sharing valuable tips and tricks from previous experiences, and gaining a deeper understanding of potential issues students may encounter.

2.4 Feasibility and Scalability

The EAGLE project at KU Leuven is resource-intensive, with a team of 20 Teaching Assistants (TAs) and 9 professors supporting approximately 80 students. While the current resource allocation allows for effective guidance and support, it is important to consider the scalability of such a project in larger institutions with cohorts of over 300+ students. Given the limited resources, it is unlikely that the EAGLE project can be directly replicated on a larger scale. However, the project's framework and principles can be adapted and modified to suit the available resources and context of different institutions. It may be necessary to explore alternative approaches, such as smaller project teams or leveraging technology for remote coaching, to make project-based learning feasible and scalable in larger student cohorts.

2.5 Evaluation

The EAGLE project, being a part of the curriculum, incorporates a robust assessment framework that evaluates students' technical achievements, soft skills development, and material handling proficiency. The EAGLE guidance team conducts evaluations using a comprehensive rubric as shown in Table 1. for all assessment moments (T1-T4) throughout the year. Following each assessment, students receive detailed feedback on their team's performance, with subscores provided for technical achievement, teamwork, and planning and organization. The rubric categorizes team performance into different levels, ranging from failing to exceptional, for individual assessment criteria.

In addition, students are required to submit self- and peer-assessments for T2, T3, and T4, which contribute to the evaluation process. Peer evaluations carry increasing weight as the project progresses, and team members assess each other based on their contributions to the process and the product. Constructive comments accompany each assessment, fostering a constructive and fair evaluation environment. This comprehensive evaluation framework ensures a fair and thorough assessment of students' performance in the EAGLE project, encompassing technical achievements, soft skills development, and material handling proficiency.

Table 1. The EAGLE comprehensive evaluation rubric

EAGLE 1		Failing	Struggling	Sufficient	Advanced	Exceptional
	Milestones					
	Comments Milestones					
ANC	Milestone technical achievement (put a '1' in only one cell)					
IMP	Milestone technical achievement (put a '1' in only one cell)					
SWIPT	Milestone technical achievement (put a '1' in only one cell)					
COMMS	Milestone technical achievement (put a '1' in only one cell)					
CRYPT	Milestone technical achievement (put a '1' in only one cell)					
Team work	**Teamwork**					
	Comments teamwork					
	Discussion (GRADED BY COACH)					
	Independence and creativity (GRADED BY COACH)					
	Commitment (GRADED BY COACH)					
Plan & Org	**Planning and organisation**					
	Comments Planning and organisation					
	Submitted plan + system level diagram (SLD) + blog (GRADED BY INTEGRATION EXPERT + COACH)					
	Daily planning process during meetings (GRADED BY COACH)					
	Organisation (GRADED BY COACH)					

3 FINDINGS AND DISCUSSION

In this section, we present the findings from student feedback and discuss the effectiveness of the EAGLE project in terms of developing collaborative problem-solving (CPS) skills and other skills outlined in the introduction. The feedback was collected through a questionnaire answered by students who participated in the EAGLE project during the 2020-2021 and 2021-2022 academic years.

3.1 Student Feedback

The questionnaire included several questions aimed at understanding the students' perceptions and experiences in the EAGLE project. Here, we highlight the key findings (shown in *Fig. 3*. to *Fig. 7*.) from the questionnaire:

Importance and Added Value: One question asked students about the most significant added values of the EAGLE project. The responses showed that students highly valued the opportunity to work on an engineering challenge in a multidisciplinary subject. They pointed out the development of teamwork and problem-solving, as essential aspects of the project's value.

Workload Evaluation: Students were asked to evaluate the workload of the EAGLE project. The findings indicated that students perceived the workload as substantial. It is important to note that the foreseen workload for the project is 250 hours, based on the number of ECTS credits assigned to the course. This feedback helps put the workload into perspective and highlights the dedication and effort required from students to complete the project successfully.

Frequency of Evaluation Moments: The evaluation moments throughout the EAGLE project were also evaluated by the students. The feedback showed that the majority of students found the frequency of evaluation moments to be appropriate. This indicates that the scheduled evaluation sessions provided students with valuable opportunities to track their progress and receive feedback at regular intervals.

Clarity of Evaluation Criteria: Students' opinions regarding the clarity, transparency, and alignment of the evaluation criteria with the objectives of the project were gathered. While the majority of students found the evaluation criteria clear and transparent, some indicated that they were not always aligned with the project's objectives. This feedback provides valuable insights into areas where the evaluation criteria can be further refined to better align with the intended learning outcomes.

Mix of Team, Individual, and Peer Evaluation: The students' opinions on the mix of team, individual, and peer evaluations were also captured. The feedback indicated that students generally appreciated the combination of these evaluation methods. They recognized the importance of both individual accountability and collaborative team performance in the assessment process.

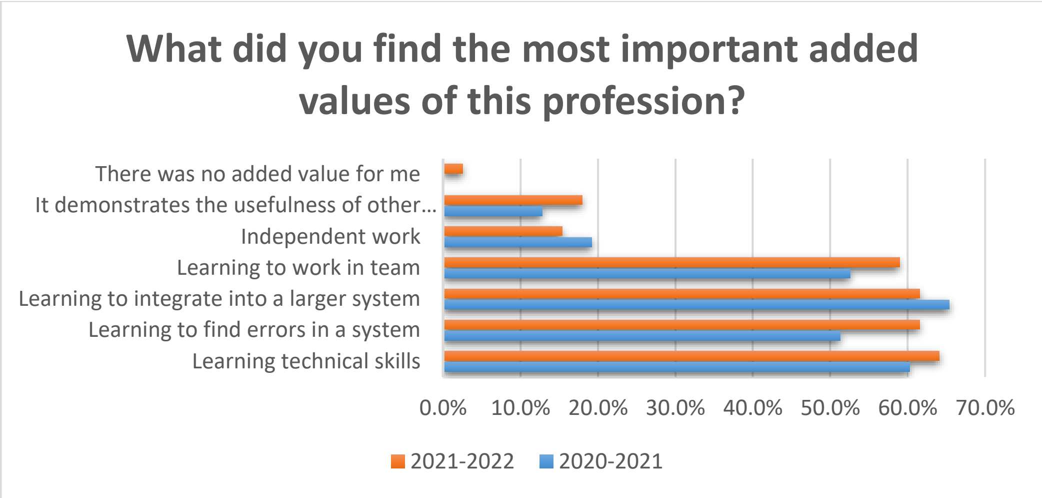

Fig. 3. Students' Perceptions of Added Values in the EAGLE Project

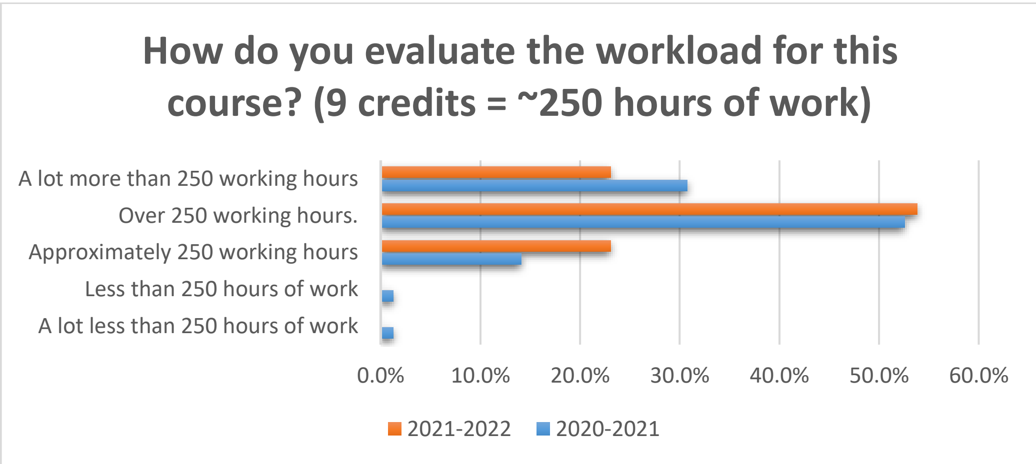

Fig. 4. Students' Evaluation of Workload in the EAGLE Project

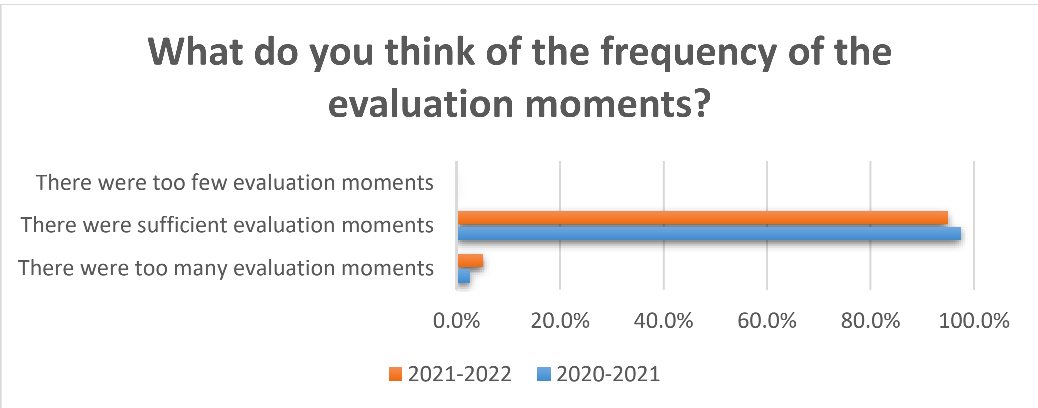

Fig. 5. Students' Feedback on Frequency of Evaluation Moments

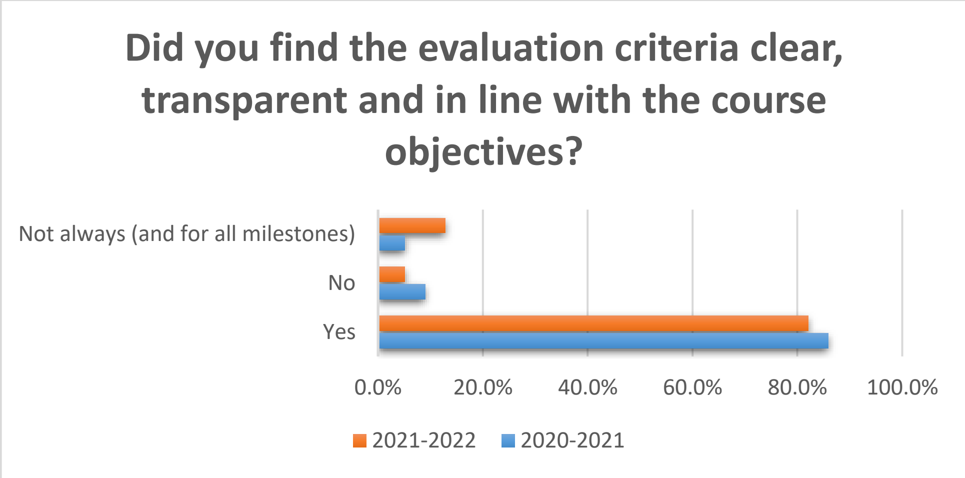

Fig. 6. Students' Views on Clarity of Evaluation Criteria

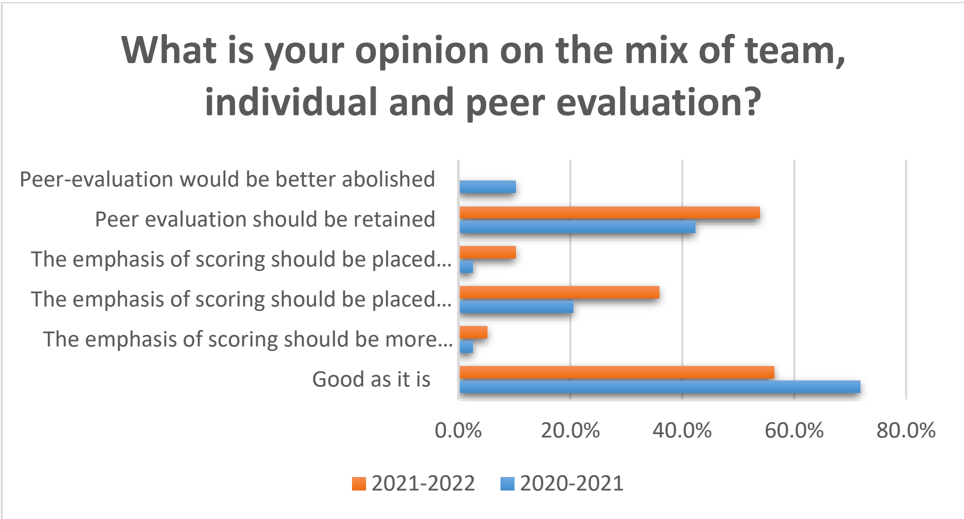

Fig. 7. Students' Opinion on the Mix of Evaluation Methods

3.2 Discussion and Implications

The findings from the student feedback provide valuable insights into the effectiveness of the EAGLE project and its impact on students' skill development. The positive feedback regarding the importance of teamwork, problem-solving, and negotiation skills aligns with the objectives of the project and supports the assertion that the EAGLE project effectively promotes collaborative problem-solving abilities.

Furthermore, the feedback regarding workload highlights the commitment and effort required from students to complete the project successfully. This information can be used to inform future iterations of the EAGLE project, ensuring that students are adequately prepared for the workload and can manage their time effectively.

The feedback on the evaluation moments, clarity of evaluation criteria, and the mix of evaluation methods offer valuable insights for improving the assessment process. By addressing students' concerns and refining the evaluation framework, the EAGLE project can continuously enhance the learning experience and provide more aligned assessment criteria.

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