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Validation of a structured role assignment methodology in group work for engineering courses

Validación de una metodología de asignación estructurada de roles en el trabajo en grupo en asignaturas de ámbito ingenieril

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HIGHLIGHTS

- Role-based group formation increases participation.
- Roles equilibrados mejoran la dinámica de equipo.
- Balanced roles improve team dynamics.

RESUMEN

La incorporación de actividades de trabajo en equipo en los programas de formación universitaria es esencial, ya que es una de las habilidades más valoradas para los profesionales en el campo de la ingeniería. La selección de los grupos de trabajo por parte del profesor es una estrategia que puede conducir a un mejor desempeño en las tareas colaborativas. Este estudio presenta los resultados de una investigación sobre los criterios conscientes para la selección de grupos de trabajo basados en los roles de los estudiantes. La investigación tuvo como objetivo analizar las dinámicas de trabajo en equipo entre estudiantes de diversas disciplinas dentro de los cursos de ingeniería. Se examinaron las opiniones de más de 600 estudiantes matriculados en 10 programas de grado y posgrado. Los resultados indican que los estudiantes de cursos avanzados se sienten más cómodos asumiendo el papel de líder, mientras que los estudiantes de primer año no tienen un perfil claramente definido. La evaluación de los estudiantes con esta metodología también muestra ciertas variaciones dependiendo del año y el tipo de actividad. En general, en los grupos con mejor rendimiento, la mayoría de los miembros reciben evaluaciones similares de sus compañeros.

Palabras clave: *Trabajo en equipo, grupos de trabajo, habilidades de los estudiantes, educación superior, roles de conducta.*

ABSTRACT

The incorporation of teamwork activities in university training programs is essential, as it is one of the most valued skills for professionals in the field of engineering. The selection of working groups by the teacher is a strategy that can lead to better performance in collaborative tasks. This study presents the results of research on the conscious selection criteria for group work based on students' roles. The research aimed to analyze teamwork dynamics among students from various disciplines within engineering courses. The opinions of over 600 students enrolled in 10 undergraduate and postgraduate programs were examined. The results indicate that students in advanced courses feel more comfortable taking on the role of leader, while first-year students do not have a well-defined profile. The evaluation of students using this methodology also shows certain variations depending on the year and type of activity. Overall, in the highest-performing groups, most members receive similar evaluations from their peers.

Keywords: *Teamwork, working groups, students' skills, higher education, behavioral.*

1. INTRODUCTION

The traditional educational programs, based on the evaluation of disciplinary contents, were transformed into others where different competencies and skills of students can be evaluated [1]. This change was due to the establishment in Europe of the European Higher Education Area (EHEA) in 1999, through the Bologna process, to facilitate student and faculty mobility and make higher education more inclusive, accessible and competitive worldwide [2]. Therefore, subjects and their training activities have been adapted to these new learning outcomes [1]. Based on this, when designing the curriculum of a subject belonging to higher education, two different types of competencies to be acquired by students once they have passed the specific subject must be specified [3,4]:

- General competencies, which are key competencies and transferable to a wide variety of personal, social, educational and work situations.

- Specific competences, which are more specific to the subject and are focused on achieving essential knowledge for when the student graduates and faces the employment market.

Within the latter competences, it is worth mentioning the relevance that has in practically all higher education subjects related to some branch of engineering, the ability to work in a team, which is crucial both to optimally perform higher education studies and to develop their professional work in the future. In fact, the ability to communicate and work effectively in a team is one of the skills most in demand by engineering companies [5].

However, many factors affect the success of teamwork: group composition, lack of creativity, mastery or indifference of teammates, little or even absence of lead, personality classes and, most relevant, the conflicts related to an unequal effort and contribution by the members of the team to the task [6]. Therefore, the way of forming working groups is crucial to evaluate this ability and its adequate development by the students [7]. Typically, the workgroups are created following three pathways: alphabetical order, random selection or student selection regarding their own affinities. Alphabetical order or random selection is easy for the teacher, and all groups exhibit the same opportunities to carry out the task successfully [8]. The formation of groups by students is based on their friendship, geographical proximity, similar class schedule or choosing a classmate due to their best academic marks. In this way, probably, the group is unbalanced in skills, and aptitude against the overall performance for the entrusted task, increasing the probability of failure compared with the formation of groups randomly [6,9]. Moreover, in both types of team formation, the level of participation is not always the same for all members, so the developing of the corresponding team competence is not accomplished homogenously [10]. Therefore, these methodologies do not consider the students' skills and how they can help to carry out the task optimally, achieve better learning results and improve marks.

Concerning learning in groups, two different approaches have been differentiated in the literature: cooperative and collaborative learning, which are often used synonymously but exhibit some differences, resumed in Table 1 [11].

***Table 1**: Approaches differentiated in learning in groups.*

Name	Definition
Cooperative learning (CooL)	CooL implies group work without any interaction between the students
Collaborative learning (CIIL)	CIIL always includes interaction, collaboration, and utilization of the group's skills, promoting academic achievement and collaborative abilities

In this way, different methods have been employed in higher education to develop collaborative learning correctly, demonstrating that they help reduce the difficulty associated with working groups and the students' correct acquisition of these skills. For example, the peer evaluation [12] and the student self-assessment surveys to know the perspective of each student during the activity, or even the combination of both (called 180º evaluation) [2,13], can help to identify students' strengths and weaknesses, to develop their critical spirit constructively and to take responsibility and engage more with their learning [2], as long as the teacher directs them well. However, in peer evaluation, the students tend to form a cooperative group, not a collaborative one; therefore, they cannot

optimally maximize their abilities for their benefit and the entire working group [14].

Another widely used team-forming method to develop collaborative learning is based on classification by students' roles [15–18], and the Belbin role theory is the most accepted worldwide [6,19–22]. Belbin proposed the categorization of individual behaviour within the team into nine roles (Figure 1): Monitor Evaluator, Plant and Specialist (roles oriented to thinking and solving problems); Shaper, Implementer, Shaper and Completer and Finisher (action-oriented roles); Coordinator, Resource Investigator and Teamworker (people-oriented roles) [6].

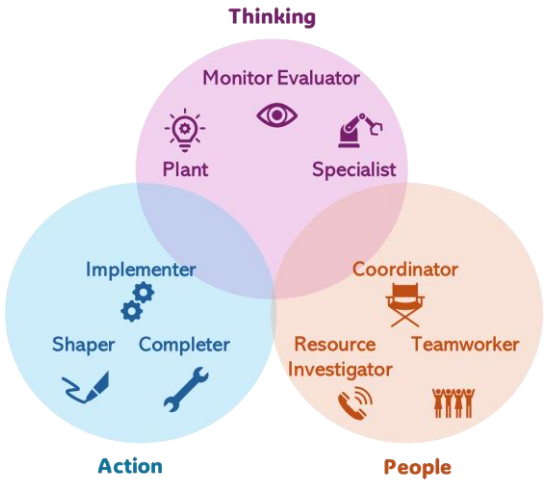

Fig. 1: *Nine roles proposed by Belbin.*

However, the Belbin method could imply that a student would have to develop more than one role in a work team, even 2 or 3, being confirmed that if the group is less than five people, all the skills proposed by Belbin are not covered [23]. In addition, it should be noted that if this method is applied in the first or second year of higher education and due to the lower maturity of the students, the high number of proposed roles will tend to confuse them more than cause learning benefits and the proper development of the competence to work within a team.

Based on the categorization previously mentioned, the present study proposes the effective management of collaborative working groups applied in engineering higher education through different behavioural roles: leader, collaborative, thoughtful and creative [24, 25]. The teacher can efficiently perform the methodology to form the groups (questionnaire with 40 questions, 10 per role, employing Microsoft Forms and Excel) and aims to be attractive and friendly for the students. Compared to other published methods based on roles, the main advantage is that the questionnaire created for the role assignation is free and will be available online. Moreover, the smaller number of proposed roles fits perfectly with the members that usually form work teams in engineering degrees. On the other hand, this classification expects each group to have at least one type of role to maximize their abilities to benefit themselves, the group and the proposed task. Afterwards, the students were surveyed about the methodology used, and the academic results of both the subject and the training activity were compared to previous courses in which the teacher randomly formed the groups.

2. MATERIALS AND METHODS

2.1 Behavioural roles definition and questionnaire description

This study proposes the effective management of collaborative work groups applied in higher engineering education through four behavioural roles, which are not mutually exclusive, and team members can assume multiple roles based on their strengths and the needs of the team. Effective teams can leverage the strengths of each of their members and work together to achieve their goals.

Previous studies have highlighted the importance of different roles individuals assume within a team to maximize performance and creativity in teaching [24, 25]. According to these studies, the figure of the *leader* is crucial for guiding the group toward a common goal. A leader, as these studies suggest, is a mature and self-confident person, highly motivated to achieve their objectives. This role can coordinate the abilities of others, fostering collaboration and resolving problems when they arise. Leaders are typically open to listening to and analysing different perspectives, but they can be blunt and authoritarian when they deem an idea unreasonable.

On the other hand, the role of the *collaborator* is associated with practical and disciplined individuals who prefer to work systematically, even if it means taking on a heavier workload. Collaborators are flexible and adaptable, with a marked tendency to prioritize the group's success over personal achievements. Research shows that this role is key to team cohesion, although collaborators can sometimes be indecisive when making decisions.

Another essential role in team settings is that of the *thoughtful* member, characterized by their prudence and ability to critically analyse problems and evaluate ideas. These individuals tend to be more introverted, prefer working independently, and often take on significant tasks without delegating. Their contribution is particularly valuable in the analysis and evaluation phases of projects, where their accuracy in judgment becomes a critical asset for the group.

Finally, the *creative* role has been identified as fundamental in the initial stages of an innovation project. Creative members are innovative, independent, and original, with the ability to generate new ideas for the team. However, studies have pointed out that they may lose motivation if they feel the project is not progressing as expected, and they sometimes struggle to communicate or "sell" their ideas to the group. Together, these roles interact in a complementary manner, creating a work dynamic that, when well-managed, drives innovation and success in educational settings.

Once these behavioural roles have been defined, it is necessary to describe the questionnaire that has been developed to assign a predominant role to each student. 10 characteristic affirmations of each role have been elaborated, in which the students will be asked their degree of agreement or disagreement with an affirmation. As previously mentioned, there are 4 roles. Therefore, it consists of 40 statements, which appear to the students randomly so as not to condition the responses. It is possible to consult the questions in the previous works [24, 25].

In order for students to answer this questionnaire easily, the statements have been prepared in the Microsoft Forms tool. Each subject under study has its own quiz, found below. Later, the teacher can easily view all the response data of his students and export it to Microsoft Excel. An Excel workbook containing the response data of all students will be downloaded and processed to assign the majority role to each student based on their responses. To carry out the assignment, each role is analysed separately. Its assessment is made based on whether the student agrees with the statement. It has a value of +1, and if, on the contrary, they disagree, it has a value of -1. The sum of the 10 questions for each role would give rise to the score for each role. The characteristic affirmations or sentences of each role will be shown below.

2.2 Subjects and activities under study

The methodology was explained to the students, the questionnaire was sent to those enrolled in the different subjects covered in this study (Table 2). The teaching staff invests effort in trying to explain that collaborative work should maximize individual capabilities for the benefit of the individual, the group and the proposed task.

***Table 2**: Subjects of different grades/master studies.*

	Subject (Course/ Semestre)
ENERGY ENGINEERING	Experimentation in energy engineering I(3/I)
	Experimentation in energy engineering II (3/II)
INDUSTRIAL ELECTRONIC & AUTOMATIC	Graphic expression (1/II)
	Applied thermodynamics (2/I)
CHEMICAL ENGINEERING	Experimentation in chemical engineering II (2/I)
	Experimentation in chemical engineering III (3/II)
	Engineering projects (4/I)
WATER RESOURCES	Fundamentals of water treatment technologies (3/I)
	Water potabilization (3/II)
INDUSTRIAL TECHNOLOGY ENGINEERING	Applied thermodynamics (2/I)
ENVIRONMENTAL ENGINEERING	Atmospheric pollution treatment technologies (3/II)
MECHANICAL ENGINEERING	Hydraulic and pneumatic machines (3/II)
INDUSTRIAL ORGANIZATION ENGINEERING	Engineering projects (4/I)
NANOSCIENCE AND NANOTECHNOLOGY	Thermodynamics and catalysis (2/II)
MASTER'S IN INDUSTRIAL ENGINEERING	Chemical processes and products (1/I)

The students were informed of the project and the purpose of the method, and it was necessary to complete a questionnaire to be included in the collaborative working groups of the different training activities. All subjects belong to the Chemical Engineering Area of the Faculty of Experimental Sciences of Rey Carlos University (Móstoles, Madrid, Spain). The number of participants involved in the study was a total of 635 students of 9 engineering degrees and master studies with 3 different group activities:

- Laboratory: The total students are divided into teams of 4 members, who will work together to prepare and develop different experimental developments. Subsequently, they must prepare a joint report and pass an individual exam.

- Project-based learning: As in the previous activity, all the students are divided into teams of 3-4 members working on a project to solve a real-world problem related to the subject. Students demonstrate their knowledge and skills by proposing a realistic solution to the problem posed. In addition, they must perform an oral communication and a report.

- Problem-based learning: students learn about a subject by working in groups to solve an open-ended problem.

Following implementation of the methodology, students were surveyed to gather their perceptions using a questionnaire, which included the overall rating as well as a series of statements designed to evaluate various aspects of the methodology. Students were asked to respond using a Likert scale, indicating their level of agreement or satisfaction with each statement. The scale ranged from 1 to 5, with 1 representing “totally dissatisfied” and 5 representing “totally satisfied”; the statements are summarized in Table 3. In addition to rating their satisfaction, students were encouraged to provide qualitative feedback on specific elements of the methodology. This included their opinions on the clarity of instructions, the relevance of the

methodology to their group work, and the overall effectiveness of the methodology for their learning. By combining quantitative data from the Likert scale with qualitative information from open-ended responses, a comprehensive understanding of student perceptions was obtained.

***Table 3**: Statements used to understand students' perceptions.*

	Definition
Q1	This way of forming groups has seemed interesting to me.
Q2	The established roles seem adequate to me (leader, reflective and creative collaborator)
Q3	The formation of groups by roles has been effective in the experimental development of laboratory practices or group work.
Q4	I have been able to develop my role adequately within your group.
Q5	My work group by roles has worked better than those formed following traditional methods.

The data collected was then analysed to identify trends and areas for improvement. This analysis aimed to highlight both the strengths and weaknesses of the methodology, providing valuable insights for future iterations of the learning process. The goal was to ensure that the methodology supported their learning and development in a meaningful way.compared to other ones in which the teacher randomly formed the groups.

3. RESULTS AND DISCUSSION

3. RESULTS

3.1. Predominant student behavioural role

In this section, the roles of predominant behaviour regarding the answers of the students in the questionnaire are analysed. As explained, students have been previously informed about this methodology, and all students enrolled in the subjects must respond the questionnaire during class.

The global results are depicted in Figure 2, in which the percentages of the four types of roles have been summarized. The role with the highest percentage is leader, with more than 34%.

The next role with the highest percentage is that of thoughtful, with more than 25%, which corresponds to a quarter of the group; therefore, it is the role that achieves an adequate average representation. And finally, the role of creative and collaborator are those that reach the lowest percentages of the total class (around 20% each).

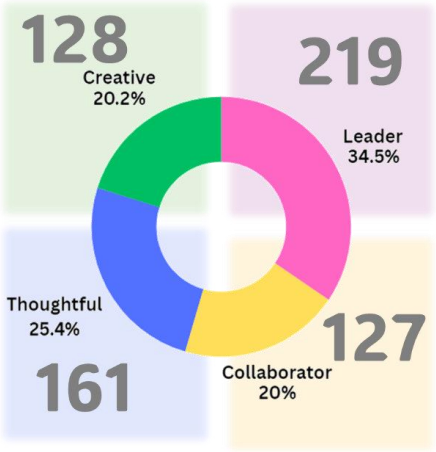

***Fig. 2:** Behavioral roles distribution for engineering students.*

Based on the above results, it can be stated that these future engineers seem to have a clear leadership role, as described in the literature, using the Belbin methodology [6] and with other types of strategies to measure student behaviour [21]. Instead, only a small proportion of engineering students present fundamental behavioral roles such as creative or collaborator, indicating that these types of related tasks must be carried out by all members or, in future work, other professionals will carry them out.

However, if the subjects are analyzed separately, according to the course or year in which they are taught, these distributions are not repeated in all the subjects of the different stages of the formative itineraries. For this reason, Figure 3 shows the distributions by different stages or courses. From the first course, based on basic training subjects in the industrial branch, an unbalanced proportion of roles is observed, although the role with the highest proportion is that of leader and a small part of the students consider themselves collaborators. However, at this stage, the students have just begun their studies and have not done enough group work to be able to draw clear conclusions.

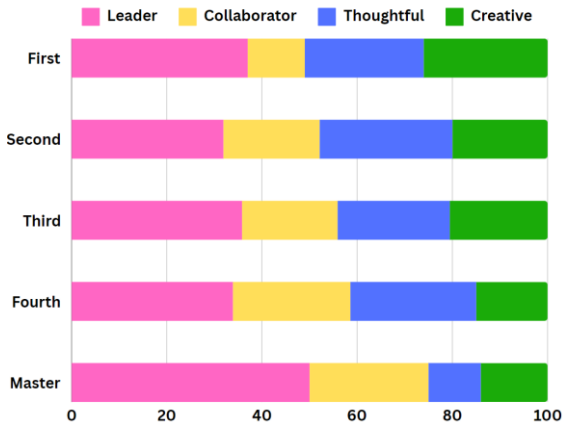

Fig. 3: *Behavioral roles distribution for engineering students by steps.*

More interesting and balanced distributions are shown when analyzing the results obtained in the second- and third-year subjects (Figure 3), observing a slight lack of collaborative and creative roles, whose functions are performed by students considered leaders. This analysis reveals that, as students advance in their training, the distribution of roles becomes more balanced, although a predominance of leadership roles is still perceived.

When analyzing the last year of the degrees, the results (Figure 3) show that the creative role is the least predominant; however, the other three roles present a more even distribution. This trend is repeated in the next stage of studies, which corresponds to Master's studies, where the majority role continues to be that of leader, while the reflective or creative roles are in the minority.

Thus, the maturity level of the students leads to a less balanced distribution of the different roles proposed. This phenomenon suggests that, as students progress in their academic training, they tend to assume leadership roles more frequently, possibly due to greater confidence and experience acquired throughout their studies. However, this also indicates a need to encourage more collaborative and creative roles in order to achieve a more appropriate balance in the development of interpersonal and innovation skills.

3.2. Perception of students about the group selection methodology

In order to know the opinion of the students about the success of the proposed methodology in the management of work groups by behavioural roles, the students have been asked to rate it from 0 to 10. It can be observed in Figure 4 that the opinion of the students is positive, obtaining an average value of 6.8.

Fig. 4: *Histogram of students' assessment of this methodology.*

Regarding the results obtained with the survey that allows to evaluate various aspects of the methodology. The statements, collected in Table 3, measure different aspects of the group formation methodology and the assignment of roles within the groups. Q1 evaluates the students' interest in the method used to form the groups, seeking to understand if this form of grouping is attractive to them. Q2 focuses on the appropriateness of the roles established within the groups, such as leader, reflective collaborator and creative collaborator, and whether these roles are considered appropriate by the students. Q3 measures the effectiveness of role-based group formation in the experimental development of laboratory practical or group work, assessing whether this methodology has improved performance in these activities. Q4 reflects students' self-assessment of their ability to adequately perform their assigned role within the group, providing insight into their confidence and competence in their role. Finally, Q5 compares the performance of role-formed groups with those formed using traditional methods, determining which of the two approaches is perceived as more effective by students.

The results showed in Figure 5, that most students were satisfied with the clarity of the roles established, being very satisfied with the ability to adequately perform the assigned role within the group, which can be translated into an idea of their confidence and competence in their role. Students often negatively value group work, especially when teachers assign their peers. This forced assignment often results in coordination and communication problems within the group. Students may feel uncomfortable or frustrated when having to collaborate with people with whom they have no affinity or with whom they do not share similar work styles. These difficulties can affect the efficiency and quality of group work, resulting in a less positive and productive experience for students. However, some students pointed out areas for improvement, especially in the effectiveness of the methodology for their learning. The combination of quantitative data from the Likert scale with

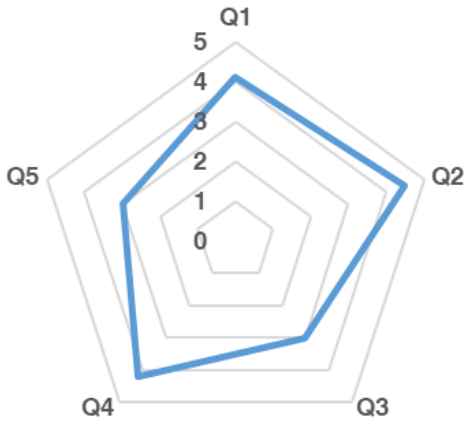

Fig. 5: *Evaluation of the methodology* **.**

qualitative information from the open responses provided a comprehensive understanding of students' perceptions.

Therefore, the students value this methodology positively, since it tries to achieve a balanced distribution of roles. However, in the free text questions, their reflections show that in some cases it was not possible, although they do consider that they have improved their involvement in the teamwork dynamics. Some of the students commented that having a clear structure and defined roles facilitates collaboration and minimizes conflicts, which results in a more enriching and productive learning experience. The analysis of the data also revealed significant trends and areas for improvement. For example, strengths were identified in the structure and clarity of the methodology, while adjustments were suggested to improve student collaboration and engagement. These results provided valuable insights for future iterations of the learning process, with the aim of ensuring that the

methodology not only accurately assessed student performance but also supported their development and learning in meaningful ways.

4. CONCLUSIONS

In this study, we have applied an innovative methodology to organize collaborative work in engineering courses, at no cost to students. This methodology allows teachers to efficiently select group members by implementing a 40-question questionnaire, with 10 questions for each role, using accessible tools such as Microsoft Forms and Excel. The objective is to make this methodology attractive and friendly to students, facilitating their participation and engagement.

The resulting classification ensures that each group has at least one representative of each type of role (leader, reflective collaborator and creative collaborator), thus maximizing individual capabilities for their own benefit, that of the group and of the proposed task. The results indicate that students value this methodology positively, since it promotes a balanced distribution of roles and improves teamwork dynamics.

In addition, this methodology not only optimizes coordination and efficiency in group work, but also fosters the development of interpersonal and leadership skills among students. By providing a clear structure and defined roles, collaboration is facilitated, and conflicts are minimized, resulting in a more enriching and productive learning experience.

5. ACKNOWLEDGEMENTS

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