Monitoring questionnaires to ensure positive interdependence and individual accountability in a chemical process synthesis following collaborative PBL approach

A. Aranzabal*, E. Epelde, M. Artetxe.

Department of Chemical Engineering, Faculty of Science and Technology, University of the Basque Country (UPV/EHU); P.O. Box 644, 48080 Bilbao, Spain

*E-mail: asier.aranzabal@ehu.eus

HIGHLIGHTS

- Monitoring questionnaires (MQs) allow rating individual accountability in team work.
- MQ allow measuring whether teammates know the essential aspects of the project.
- MQs are generic, succinct and quickly answered in classroom.
- Different individual rating methods based on weighting factors (WF) are analyzed.
- WF3 =individual rating / (the team’s highest rating x factor) showed best results.

ABSTRACT

Teammates in a Project Based Learning (PBL) methodology do not all start with the same motivation, expectations or self-commitment, which can lead to disappointing learning experiences. Thus, the main difficulties in cooperative learning are promoting positive interdependence and individual accountability. This work aims to analyze whether monitoring questionnaires (MQs) allow rating each teammate's individual accountability in a chemical process design project. Students took MQs just after finishing each deliverable, in order to verify each one's knowledge of the essential aspects of the team project. We assume that, if all the teammates work responsibly and cooperatively, they will be able to answer the MQs easily and correctly. The MQs were designed to be: 1) generic; 2) succinct; and, 3) quickly answered in the classroom. In addition, different rating methods were analyzed to incorporate MQs scores into each individual's project grade. The best results were obtained when student's individual grade was computed as the product of the team assignment grade and the weighting factor WF3, calculated as the individual average MQs rating divided by the highest MQs rating in the team. A compensation factor (0.75-.0.85) was included to correct the excessive downgrading for students with intermediate project grade.

Keywords: Project based learning (PBL); cooperative learning; teamwork; rating; individual accountability; questionnaires

1. INTRODUCTION

Research and the latest trends in engineering education highlight the importance of knowledge being built around practice, creativity and innovation (Freeman et al., 2014). The Higher Education Area, through the Bologna Declaration, promotes student-centered competency-based education rather than teacher-centered lecture-based education. Glassey (2018) highlights the latest global trends in active learning on chemical engineering such as open-ended problems, long term projects or teamwork skills. This has prompted many universities, faculties and teaching teams to modify the lecture-based teaching into a more active way of teaching, such as Problem Based Learning (PBL), which is one of the most commonly used educational methods in medical schools in different countries (Bate et al, 2013; Frambach et al. 2012), and is also being implemented in science and engineering education (Aranzabal, 2014; Elham, 2017; Gandhi, 2017). Working through PBL, on the basis of an open and ill-structured problem, students think critically, generate ideas and acquire the knowledge and skills required to become a professional. PBL has been applied globally in a variety of professional schools, so that the type of the problem used varies from one area to another, depending on the nature of the discipline. In the engineering field, design problems are commonly used. These problems are the most complex and ill-structured ones and require a high degree of knowledge (Jonassen and Hung, 2008). This variation of PBL is called project-based learning (Mills, 2003). Hadinm and Esche (2002) reviewed the roots of project-based learning and the benefits of introducing this educational method in the engineering curriculum. According to Woods (2012) the outcomes, the knowledge acquired and the overall learning experience are different between problem-based and project-based learning. The latter demands a previous learning to solve the project. However, both modalities have in common that the learning process takes place cooperatively, so that students work together to maximize individual and group learning. The objectives of the group members are so closely linked that their success in achieving these objectives depends solely and exclusively on the other members of the group also achieving theirs (Johnson et al., 2006). Cooperative learning aims to improve students' communication and teamwork skills, which are essential in the professional context of the 21st Century.

On PBL medical schools, like in McMaster (Canada), up to ten students work together supervised by a tutor during PBL tutorial sessions (Wun et al., 2007, Frambach et al. 2012, Woods, 2012). The tutor's role is primarily to facilitate the development of thinking, problem solving, clinical, troubleshooting, detective, as well as team-working skills (Hmelo-Silver and Barrows, 2006). However, in engineering courses there is usually only one teacher for every 20 - 60 students, so each group of students tackle the problem in a self-directed way without tutoring (Woods, 2012). A disadvantage of this approach is that all group members may not start from the same motivation, expectations or self-commitment, so the engagement of some members can be weak, not to mention that some members can be true hitchhikers and free riders (Oakley et al., 2004; Yi-Ming Kao, 2013). Besides, the dominance of a single member in a group must be avoided (Johnson and Johnson, 1999). All these situations can lead to unpleasant learning experiences. The presence of a tutor by large eliminates this type of concern (Nisbet et al., 2014). Walsh (2005) defines the roles of the tutor in a PBL session: Climate setting —create a safe, conductive environment for self-directed learning—; Planning —organize and structure of tutorials—; Clarifying learning needs —frame learning objectives and set goals—; Designing a learning plan —help students with learning plans and develop strategies—; Engaging in learning activities —guidance to ensure that students are on track with their learning—; Assessing learning outcomes —include formative feedback as well as summative assessment. Many research studies have identified and categorized the relationship between tutors' behaviour and students' outcomes. Williams and Paltridge (2016) summarize the key findings of such researches.

Johnson et al. (2006) describe five basic ingredients that a successful cooperative learning experience must meet (Table 1): (1) positive interdependence, (2) individual and group accountability, (3) face-to-face interaction, (4) interpersonal skills and (5) group processing. All the ingredients are important, however, the most difficult to achieve are the positive interdependence and the individual and group accountability (Jensen et al., 2002; Johnson and Johnson, 2009; Laal, 2013; Laal et al., 2013; Scager et al., 2016). The contribution of all the group members is necessary to complete successfully the group's task, and no member should ignore the colleagues' work or focus only on a small part of the work.

TABLE 1

Different strategies are described in the literature in order to ensure these basic elements (Oakley et al., 2004; Woods, 2012). Primarily, positive goal interdependence ensures that the group share a common goal. The nature, dimension and difficulty of the task must be sized so that the group members perceive they need each other in order to complete the group's task; otherwise, if there is no positive interdependence there will no be any cooperation. Ways to incorporate positive interdependence are (Brewer and Klein, 2006; Jensen et al., 2002; Johnson et al., 2007; Scager et al., 2016; Sears and Pai, 2012): resource interdependence, goal interdependence, reward interdependence, role interdependence and task or sequence interdependence among others. Individual accountability is promoted by providing opportunities for observing and assessing the performance of individuals by others (Laal et al., 2013). Common ways to boost individual accountability are individual quizzes or examinations. Other measurements that the teacher can implement are (Chelminsky, 2017; Felder and Brent, 2001; Kaufman, 2000; Stanton and Fairfax, 2007; Veenman et al, 2005): to keep the size of the group small (three to five students); to process the group's and the individual's contributions; to introduce peer assessment; to randomly check students comprehension; to boost peer teaching; to assign the role of the checker in order to verify that all team members understand both the solutions and the problem-solving strategies; to use vertical slicing, where each student, in parallel to the project, must individually handle a portion of the task at each level of development, etc.

Benefits of peer assessment have been extensively analyzed in the literature. Many peer rating systems for teams and procedures for using the ratings to adjust group grades for individual performance have been described (Adachi et al., 2018; Ashenafi, 2017; Brown 1995; Kaufman, 2000; Lejk and Wyvill, 2001; Li, 2017; Oakley et al., 2004; Patchan et al., 2017; Roberts et al., 2017; Wanner and Palmer, 2018; Yi-Ming Kao, 2013). Peer assessment enables the students to partly assume responsibility for the assessment process. This method is popular in both face-to-face and online environments (Bouzidi and Jaillet, 2009; Hearn et al., 2017). Peer assessment can be divided into holistic and category-based approaches (Lejk and Wyvill, 2001). The holistic approach supports the purposes of summative peer assessment methods within the group project work better than the category-based approach. However, the category-based approach is useful for formative assessment. The holistic approach can be carried out by assessing relative contributions of the team members to the final product, usually expressed as percentages of the total effort or by assessing team membership, which stresses teamwork skills (cooperating with the team, fulfilling responsibilities and helping others) over academic skills which might result intrinsically competitive and favor the team members who are academically the strongest (Oakley et al., 2004). However, peer assessment is not always effective and some common concerns have been widely discussed in the literature, which are similar to those we have formerly experienced. Usually students: 1) agree to give one another identical ratings; 2) inflate or deflate their self-ratings; 3) give ratings based on personal prejudices; and, 4) complain about having their grades affected by peer ratings (Hearn et al., 2017; Kaufman et al., 2000; Liu et al. 2001). For cultural reasons, even in an anonymous setting, some students do not dare to score their group mates with low grades and tend to rate everyone equally and with maximum score so as to avoid potential conflicts. The authors of this paper have previously experienced this situation several times, concluding that the instructor must take all the responsibility of the assessment to ensure individual accountability. Thus, research efforts are focused on developing more objective peer ratings, which should be less subjected to personal feelings (Carvalho, 2013; Cuadrado et al., 2014, VanSchenkhof et al., 2018).

In this paper we analyze whether monitoring questionnaires (MQs) allow rating each teammate's individual accountability in a chemical process design project. For this purpose, students took MQs just after they finished each project deliverable, in order to verify that each student knew the essential aspects of the team project. Our working assumptions are the same as when peer assessment is carried out; that is, if all members of the group act responsibly and cooperatively they will receive a high score corresponding to the peer assessment, and only "cooperatively problematic" students will suffer penalties (Kaufman et al., 2000). In this case, if all the members of the group act responsibly and cooperatively, they will be able to respond to the MQs easily and correctly, and therefore, get high mark.

Moreover, monitoring students' engagement to the teamwork is crucial to ensure individual accountability. Thus, the second aim of this paper is to find a suitable rating criterion to incorporate MQs scores into each individual's project grade.

2. CONTEXT

The innovation described below, was carried out in the compulsory subject 'Process and Product Engineering' (9 ECTS credits) in the 5th semester of the Chemical Engineering Bachelor Program at the University of the Basque Country (UPV/EHU) in northern Spain. The first 4.5 credits are focused on learning different strategies for the design of chemical processes. Project-based learning (PBL) has been chosen as the best teaching-learning methodology, combined with other methodologies such as the flipped classroom and computer practices to train students in process simulation using SIMSCI PRO/II 9.4 software (Schneider Electric) (Belton, 2016; Li and Huang, 2017; Qian and Clark, 2016). The driving force of the subject is a project focused on the development of a base-case design of an industrial chemical process, including its economic and profitability analysis (Seider et al., 2010; Turton et al., 2013). Some project examples are: biodiesel production process, benzene production from shale gas and dimethyl ether (DME) production from residual CO_2. 30 students enrolled in this course who performed the project in groups of 5.

Students have little experience in PBL and cooperative learning, since the generalized teaching methodology in the chemical engineering program is lecture-based teaching. Therefore, before applying PBL methodology, we provided some training sessions on teamwork, focused on the importance of positive interdependence and individual accountability on team work. Firstly, a subject-based jigsaw session (Kousa, 2015) was carried out, organized into groups of three, so as to learn fundamentals of process synthesis. The second session consisted on an instructional and reflective session on Belbin roles (Belbin, 2010), so that students could identify their two most suitable roles ("resource investigator", "teamworker", "co-ordinator", "plant", "monitor evaluator", "specialist", "shaper", "implementer", "completer finisher"). Each student wrote a short report justifying the reasons and the facts why he/she chose such roles. Using these reports students chose their teammates to form teams well-balanced in Belbin roles (Yannibelli and Amandi, 2011). Students were also asked to form gender-balanced teams although female/male ratio was 27/10. There are many papers on team forming, but there is not a clear conclusion on which is the best method. Borges et al. (2009) compared the self-selection method with a group formation method based on an algorithm aiming to achieve maximum diversity within groups and homogeneity among groups. The algorithm was based in a questionnaire to evaluate students' teamwork profiles. They found out that with the latter, there is a higher number of medium ranked groups that surpass the expectations. Hilton and Phillips (2008) compared instructor-assigned and student-selected groups, by examining student's experiences as expressed in written journals. They found out the actual grades assigned to the group projects did not differ between instructor-assigned and student-selected groups. This fact suggests that the group formation method per se was not a significantly determinant of the group project marks. Thirdly, a task-based jigsaw session (Kousa,

2015) was developed, organized into PBL teams of five, so as to find, read and analyze basic literature about the project subject. This session was the starting point of the first project deliverable. The fourth session consisted on a team game tournament (TGT) on process synthesis heuristics, organized into PBL teams of five. Before the game tournament, each member was in charge of reading and analyzing around 10 of the 53 heuristics in Seider et al. (2010). Subsequently, they had to justify through these heuristics all the design strategies they adopted in each process synthesis step. Woods (2012) reviewed university cases that found it vital to provide workshop-style training to ensure students had problem solving, self-assessment and group skills before they engaged in PBL. Throughout the project development, other actions to promote team working skills were implemented: recording team activities and progress in meeting minutes and a reflective session on group processing in the middle of the project development (inmediately after the third deliverable).

The project is divided into different synthesis steps, as described by Seider et al. (2010), where each step corresponds to one milestone and its corresponding deliverable: (1) Literature Survey, focused on the state of the art of the process; (2) Reactor Design and Simulation; (3) Separation Processes-Process Overall Design; (4) Heat Integration and Heat Exchanger Network Design; and, (5) a final report in which Economic and Profitability Analysis are included. Although the final report covered all the learning outcomes to be summatively assessed, students received feedback and formative assessment after finishing each deliverable, which helped students check for understanding throughout all the learning and project design process. Moreover, students can assess themselves each deliverable by using the rubrics provided by the instructor. However, students demanded the teacher to mark each deliverable (9%, 12%, 17%, 10% and 26%, respectively); thus, the same rubrics where used by the instructor for grading. These rubrics are summarized in Tables S1-S7 in Supplementary Information Section.

The course assessment for the first 4.5 credits is divided into three components, which are the project (60%), a final individual examination (33%) and individual quizzes (7%). The individual final examination aims to assess individually the degree of ability to achieve the learning outcomes, previously and presumably achieved by the group during the development of the project design. The minimum score is 5. This is done to promote positive interdependence and individual accountability. The individual quizzes are answered individually and on-line after reading the reference literature necessary to develop each step of the synthesis and after the first jigsaw session described above. This basic literature consists on several chapters of Seider et al. (2010) and Turton et al. (2013). In addition, video-lectures and video-tutorials for SIMSCI PRO II/9.4 software training were elaborated by the instructors in order to flip the simulation training sessions and to set aside time for team project development in classroom, as well as to ensure face to face interaction.

At the end of this course, the students are expected to gain the following learning outputs:

1. Search technical and scientific information.
2. Use appropriate heuristics to select the best design strategies.
3. Draw and interpret different flow diagrams (mainly Block Flow Diagram (BFD) and Process Flow Diagram (PFD)).
4. Simulate a process using a process simulator (SIMSCI PRO/II 9.4)
5. Apply selectivity and conversion concepts in reactor design.
6. Select the most suitable equipment for each unit operation and calculate the most appropriate design parameters.
7. Develop process heat integration using Pinch technology and design the heat exchanger network.
8. Estimate capital and manufacturing costs.
9. Perform the process profitability analysis.

3. THE INNOVATION

Our previous experience has demonstrated that that only the final individual examination is not enough to ensure individual accountability. We found several cases with unequal participation among team members, and obviously those with low participation, resulted in failing exams. The reason for this may be that some students are not aware of the negative effects of their low participation in the team's project development. Moreover, they feel the final exam as something very far and not connected with the learning process during project development. In addition, the final examination does not allow identifying a lack of positive interdependence in some groups until the end, so there is no possibility of introducing corrective actions at the right time. Cuadrado et al. (2014) reported similar problems in teamwork interdependence in the development of a design project of computer programming. This way of thinking of students is conditioned by the generalized lecture-based way of learning in the bachelor program. Usually, tasks in group work have little relevance to the final score and are poorly connected with the final examination.

As shown by Cuadrado et al. (2014), in this work we introduce an additional element so that the students are aware of the positive interdependence and individual accountability in team working from the beginning to the end. This element consisted on submitting students to MQs in order to verify that each student knew the essential aspects of the team project. Students took these questions immediately after finishing each deliverable of the team's project. These questionnaires also allow identifying the teams that may have difficulties and may need teacher involvement to help them get back on track.

We found that these monitoring questions must be: 1) generic, so that they can be answered by any student regardless the quality of each deliverable; 2) concrete, so that they can be evaluated with objectivity and quickly by the instructor; and, 3) answered in the classroom in a short period of time (less than 10-15 minutes), thus, only 3-5 questions will be asked in each questionnaire. Table 2 shows some examples of the five MQs.

TABLE 2.

4. RESULTS AND DISCCUSION

4.1. Measuring individual accountability by MQs scores.

In order to easily compare the individual accountability of different students, a parameter for its quantification is necessary. Thus, the individual accountability factor (IAF) was calculated as the average of the scores obtained in the five MQs divided by the highest average in the team. Figure 1a shows the IAF for each student grouped within its corresponding team. In figure 1b the values of standard deviations for the five marks obtained in MQs for each student (SD-IAF) are shown. Figure 1c shows the project rating (and its standard deviation) for each team. It is to note that Team G was broken up because some members of the group were acting as hitchhiker (especially out of the classroom). This uncooperative behaviour was not reflected in their IAF, since they memorized the deliverables made by the other members of the group. Thus, Team G has not been included in Figure 1 to avoid confusions.

Figure 1a shows differences in IAF within the groups which are directly related to the knowledge on the project deliverable they had just submitted before answering the MQs. Then, we can assume it is related to the level of participation of each member.

FIGURE 1

Team A is formed by 4 members very involved in the project, as can be seen in Figure 1a and 1b, which also coincides with what the teacher observed in the classroom. They share the highest IAF value and the lowest SD-IAF (lower than 1.5 in all four cases), which makes it the best project with the most regular scored deliverables (Figure 1c). A5 member have significantly lower IAF and even significantly higher SD-IAF (5.8), which suggests that it is a member with a lower participation and who is taking the lowest advantage of the learning experience by team working. This lower level of learning was also corroborated by the fact that this member failed the exam.

Team B consists of a member with strong leadership (B1) with the highest IAF and low SD-IAF (lower than 1), who is accompanied by a second highly responsible member (B2) but rather irregular in the score of MQs (SD-AIF higher than 3). The rest of the members show significantly lower IAF (0.6) and higher SD-IAF as member 5A. Thus, the high quality of the project can be mainly attributed to the strong leadership of B1 and the high participation of B2.

Regarding Team C, it seems that it is similar to Team B, with C1 acting as a leader and helped by the high participation of member C2. Besides, it can be seen that C2 is not as irregular as B2, being the value of SD-IAF=1.5. However, the project rating for Team C is significantly lower than for Team B, presumably because of the presence of a very inactive member 5C (with an IAF is lower than 0.25).

Teams D and E have in common that: i) there is no evidence of a single outstanding leader, as in the former groups; ii) many of their members with high IAF are less regular (high SD-IAF); and, iii) there is a member with a very low participation (IAF lower than 5), especially in team E. Therefore, the irregularity of the members of these groups and probably the presence of a member with a very low participation, lead to lower project rating (7.6 and 7.3 for Team D and E, respectively) and the highest standard deviation of project deliverables marks (1.1 and 1.4 for Team D and E, respectively).

Group F is more cohesive than its predecessors but their project-deliverables show the lowest quality and even all their scores in MQs. It seems that there was no a clear leader in this group, being the participation of all the members constant. However, it is to highlight that all the members had similar implication and none of them was very irregular as happened within the rest of the groups, being the SD-IAF values lower than 3 for all the members. Therefore, although the project rating is relatively low, it can be concluded that the members of this group took advantage of the learning experience by team working.

According to these results, the groups with the highest number of students with a high IAF give rise to a higher quality project deliverables on a regular basis. When participation decreases the project quality and its regularity decreases. This indicates that positive interdependence exists, and that the workload and size of the group (5 members) is quite well adjusted. Teams A and B, with the highest project rating (and the lowest standard deviation), have at least two members with strong participation which is reflected in their high IAF and low standard deviation of the score obtained in the five MQs. The MQs also help the instructor identify a lack of positive interdependence and introduce corrective actions at the right time. From the beginning we could indentify some malfunctioning within team E. The teacher took action encouraging and alerting the team about the risks of such behaviour. Later on, team working improved as shown in Figure 1. With regard to team G, although the lack of interdependence as described above was not detected, the MQs mechanism prompted an internal debate on the lack of interdependence and its subsequent break up.

These results were contrasted with the students' experience and opinion by means of a Likert scale opinion survey (1 — strongly disagree, 5 — strongly agree). Students' answers allowed us to assess their perception on the effectiveness of MQs to ensure individual accountability and promote positive interdependence. 28 of 30 students participated in this opinion survey.

Figure 2 shows the students' opinion about MQs based on their level of agreement/disagreement with the following statements: A) The degree of involvement of your colleagues in teamwork has been similar; B) The group processing session allowed to improve team functioning; C) MQs allow promoting and rating individual accountability in team working. As shown in Figure 2a, only a few admitted absolute equal participation. About 32% recognized that the involvement was similar among them, but a significant number of students did not agree with this statement (21 % of the students did not agree and 14 % were totally in disagreement). Their responses match fairly well with the IAF results shown in Figure 1a, demonstrating the validity of the IAF in determining the degree of involvement. It is to note that this survey could be influenced by the fact that socially it is frowned upon to inform on the teammates, which is also corroborated when Team G was broken and the hardworking members do not inform on the teammates up to the fourth project deliverable. Furthermore, Figure 2b shows students' opinion about group processing sessions. It can be seen that a significant number of students (38%) agree or strongly agree with the statement that the group processing session allowed them to improve group functioning, while those who disagree or strongly disagree with it raise to 25 %. Regarding students opinion about MQs, it can clearly be seen in Figure 2c that most of them completely agree with the fact that MQs allow to promote the engagement to team working, being 60 % of students in agreement with this statement and only the 15 % of the students in disagreement.

FIGURE 2

Moreover, students were invited to write a critical reflection about MQs and some of them are compiled in Table 3. It is to note that generally MQs have had a good acceptance within students and they reflect the need of evaluating teammate's participation. However, several students agreed with the fact that the participation of all the members was not always perfectly reflected. They criticized that some of them were assessed positively (especially those that read the deliverable and got good scores in MQs without participating) and some others negatively (mainly those who participated but who did not understand well some parts of the deliverable or when each team member exclusively focused on one part of the deliverable without checking the other parts).

TABLE 3.

Finally, Figure 3 shows the students' opinion about the learning method (PBL) and the achievement of the learning outcomes based on their level of agreement/disagreement with the following statements: A) Developing the project by stages and assessing intermediate deliverables improves the learning process; B) The learning method (PBL) grading system (project 60%, individual exam 33%, on-line questionnaires 7%) allows to correctly assess the learning outcomes. It can be seen that students agree with the idea of developing the project by stages or steps and that assessing intermediate deliverables have improved their learning process (Figure 3a). They also believe that the grading system allows to correctly assess the learning outcomes (Figure 3b). This favourable appreciation confirms that PBL is a suitable method for this subject.

FIGURE 3

4.2. Rating method to incorporate the MQs scores to individual's project grade

The second goal of this work is to find a rating method to incorporate MQs scores into each individual's project grade. Cuadrado et al. (2014) assigned 18% of the project mark to the MQs scores and another 18% to the average of all individual's MQs scores. Kaufman et al (2000), Oakley (2004) and Willey and Freeman (2006) discuss a peer rating system to account for individual performance in team projects, developed at the Royal Melbourne Institute of Technology (RMIT) by Professor Rob Brown (1995). They calculated a weighting factor for each team member after the teammates were peer rated. Thus, each student received a mark form each teammate. The weighting factor was computed as the student's individual average rating divided by the team average. They computed each student's individual grade as the product of the team assignment grade and the individual weighting factor.

In this work we have analyzed four possible rating methods by studying their effect on the individuals' project grade. Tables 4 to 7 show the effect of each rating method on the individuals project rating of teams B, C and F. Teams A, D and E were not included for reasons of brevity and for ease of understanding, since the effect observed on teams A, E and F were similar to the shown data.

The first method (Table 4) is that reported by Cuadrado et al. (2014). This way of rating takes into account the absolute grade of knowledge of each individual on the deliverables, and also punishes the most engaged individuals if they do not answer correctly all the questions. They also receive an extra penalty if a team member is little involved with low MQs scores. Then, this way of rating forces students to work cooperatively, as the average of all individual's MQs score needs to be as high as possible. Conversely, C5 and E5, the least involved students (MQs rating = 2.0 and 1.8) are poorly punished, and get a project rating of 6.5 and 6.1 respectively, which is even higher than the rate of any member of team F, which is not reasonable. The same happens with member A5, who is the lowest involved student (MQs rating = 5.9) among strongly involved 4 members (MQs rating = 9.5) and the highest project rating (9.5). This rating method lead to an individual rating of 8.7, similar to the most engaged members of team B.

TABLE 4

The second method (Table 5) is based on the weighting factor (WF1) reported by Kaufman et al. (2000) and Oakley et al. (2004), but using the MQs scores instead of peer rating. The WF1 for each student was computed as the student's individual average MQs rating divided by the team average rating, as follows:

$$\text{WF1}=\frac{\text{individual average MQs rating}}{\text{team average MQs rating}} \qquad (1)$$

It can be seen that WF1 for the students with the highest MQs rating is greater than 1, which increases the project grade of students B1, B2, C1-C4, F1 and F2. Kaufman et al. (2000) and Oakley et al. (2004) established a maximum weighting factor of 1.10 and 1.05 respectively, so that calculated factors greater than these values were scaled down. This way, they avoided the situation of students receiving highly inflated weighting factor by virtue of having a teammate with very low rating, such as in Team C. In this case C3 and C4 reached relatively high project mark even scoring two points lower than C1 (maximum score). Wiley and Freeman (2006) computed the square root of weighing factor calculated as Kaufman et al. (2000) and Oakley et al. (2004). Performing the square root of WF1 led to opposite effects: on the one hand, the WF1 greater than 1.20 are reduced close to 1.10 or lower; and on the other hand, WF1 lower than 1,00 are raised. The lower the WF1 is, the increasing ratio becomes more and more noticeable. In the extreme case of C5, WF1 is increased up to 71%: from 0.34 up to 0.58. Similar inflation happens for E5 and A5. Nevertheless, the promotion effect is lower than the one resulted by the method of Cuadrado et al. (2014).

TABLE 5

Table 6 shows the individual projects ratings obtained using the third method proposed. In this case the weighting factor (WF2) was calculated as the IAF reported above, that is, the individual average MQs rating is divided by the highest MQs rating in the team:

$$WF2=\frac{\text{individual average MQs rating}}{\text{highest individual average MQs rating in the team}} \qquad (2)$$

This way the weighting factor is never higher than 1, which corresponds to the individuals with the highest MQs rating. In contrast, it penalizes more severely than WF1 the students with the lowest MQs rating. This fact is significant for F4 and F5, for which WF2 makes their individual project rating be lower than 5, because the team's project rating is 6.7. In the Spanish scoring system a rating below 5 means failing the project. We think this might be a severe penalty taking into account that their WF2 is the same as B3-B5 members.

TABLE 6

Table 7 shows the fourth rating method used in which the third weighting factor (WF3) was calculated as the IAF divided by a compensating factor to correct the excessive punishment of WF2 and the excessive inflation of WF1:

$$\text{WF3}=\frac{\text{WF2}}{\text{compansating factor}} \qquad (3)$$

The compensating factor ranges from 0 to 1. The lower the value, the closer to the effect of WF2 will be. On the contrary, the higher the value, the closer to the effect of WF1. Thus, we found a good compromise for factor values between 0.75 and 0.85. Table 7 shows the results obtained for a compensating factor of 0.85. The weighting factor is higher than 1.05 only for the individuals with the highest MQs rating, and in addition, it allows the project grade of F4 and F5 to be higher than 5. Regarding to members C5 and E5 the three weighting factors (WF1, WF2 and WF3) resulted in similar low project rating due to the extremely low MQs rating, unlike with the method proposed by Cuadrado et al. (2014).

TABLE 7

5. CONCLUSIONS

In this work, a method has been proposed to evaluate individual accountability in cooperative learning activities, such as developing a process synthesis project. The method consists on submitting students to monitoring questionnaires in order to verify that each student knows the essential aspects of the team project. Students answered these questions immediately after finishing each deliverable of the design project. Although the sample size is small, it can be concluded that MQs allows to rate individual accountability of each teammate. The results have shown that MQs allow promoting the engagement to team working and identifying the lack of positive interdependence.

Four rating methods to incorporate MQs scores into each individual’s project grade were analyzed. It was concluded that the best method was that in which each student’s individual grade was computed as the product of the team assignment grade and the weighting factor for that student. The weighting factor (WF3) should be calculated as the individual average MQs rating divided by the highest MQs rating in the team, including a compensation factor (0.75-.0.85) to correct excessive penalty for students with intermediate project marks.

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FIGURE AND TABLE CAPTIONS

Figure 1. The individual accountability factor (IAF) for each student (a), the value of standard deviation of the score obtained in the five MQs (SD-IAF) for each student (b) and the project rating (and the value of standard deviation) for each team (c).

Figure 2. Students' opinion about MQs by means of Likert scale: A) The degree of involvement of your colleagues in teamwork has been similar. B) The group processing session allowed to improve team functioning. C) MQs allow promoting and rating individual accountability in team working.

Figure 3. Students' opinion about MQs by means of Likert scale: A) Project developing by stages and by assessing partial deliverables improves the learning process. B) According to the learning method (PBL), grading system (project 60%, individual exam 33%, on-line quizzes 7%) allows to assess correctly the learning outcomes.

Table 1. Basic ingredients of cooperative Learning (adapted from Laal, 2013, Johnson et al., 2006)

Table 2. Some examples of the monitoring questionnaires

Table 3. Students’ critical reflections about MQs.

Table 4. Individual project rating following the method reported by Cuadrado et al. (2014).

Table 5. Individual project rating by WF1 computed as the student’s individual average MQs rating divided by the team average.

Table 6. Individual project rating by WF2 computed as the student’s individual average MQs rating divided by the highest MQs rating in the team.

Table 7. Individual project rating by WF3, calculated as the IAF divided by a compensating factor of 0.85.

Table 1.

1. Positive interdependence: Team members perceive that they need each other in order to complete the group's task. Students must believe that they are linked with others in a way that one cannot succeed unless the other members of the group succeed (and vice versa). Students must work together to get the job done.
2. Individual Accountability/Personal Responsibility: Two levels of accountability must be structured into cooperative lessons. The group must be accountable for achieving its goals and each member must be accountable for contributing his or her share of the work. Individual accountability exists when the performance of each individual is assessed.
3. Face-to-Face Promotive Interaction: Groups should have an opportunity to do some of the work in meetings where they can interact face-to-face to help each other accomplish the task and promote each other's success.
4. Interpersonal and Teamwork Skills: Contributing to the success of a cooperative effort requires teamwork skills. Collaborative skills include leadership, decision-making, trust-building, communication and conflict-management skills.
5. Group Processing: Groups need the opportunity to discuss and asses how well they are achieving their goals and maintaining effective working relationships. This enables learning groups to focus on group maintenance, facilitates the learning of collaborative skills, ensures that members receive feedback on their participation and reminds students to practice collaborative skills consistently.

Table 2.

Milestones 1. Literature Survey

- Name the two most relevant processes for methane aromatization and explain briefly the differences between both processes.
- Name the two main products derived from benzene in the chemical industry.

Milestones 2. Reactor Design and Simulation

- Which is the most abundant compound at the reactor outlet? Why?
- The reactor must be heated or cooled? Explain your response.

Milestones 3. Separation Processes-Process Overall Design

- Draw a Block Flow Diagram (BFD) showing the sequence of the separation methods selected for your process. Indentify the products separated in each unit.
- Identify the final destination of each compound (final product, byproduct, reactant…)

Milestones 4. Heat Integration and Network Design

- How did you establish Pinch temperature? Explain briefly the procedure followed and give the Pinch temperature value obtained.
- Which type of cold utility have you used to satisfy the minimum energy requirements?

Milestones 5. Economic and Profitability Analysis

- Which equipment contributed to the highest investment?
- Which costs account for the highest contribution of the manufacturing costs?

Table 3.

I don't think it's a bad idea, but I think these questionnaires don't always reflect the degree of participation. In fact, each member has a different role and abilities. For example, if you are good at calculation, it has advantages over questions related to calculation, but that doesn't mean that the rest of the members have not participated.
Monitoring questionnaires are good for determining whether you have participated in teamwork. However, I suggest more general questions. Some are quite specific.
I find them adequate because they show whether you are really involved in the project.
It may happen that one day you don't know how to answer the questionnaire, which doesn't imply that you are not involved in the project. There are many factors that can lead you to respond badly.
I think it's a very good tool for us to get an overall knowledge of each deliverable.
In this way we are working on the subject progressively and if doubts arise we can also clarify them progressively, rather than at the end of the semester.
I think they're a good strategy for learning. When you get the mark, you know whether you should try harder.
I think it is a good method to know the degree of involvement of each of us. It also encourages reflection.
Sometimes some members who get little involved, memorize the deliverable and get a high score on MQs. Therefore, I believe that it is not appropriate to determine who works and who does not.
I think MQs force you to involve in teamwork. However, you may occasionally respond badly because you don't understand the question well, even though you have been fully involved.

It is evident that the pace of each student's work is different. I suggest a tutorial session with the teacher once a week, to force everyone to get more involved.

Although the MQs make it possible to detect a lack of involvement, I believe that it is sometimes difficult to inform against members who do nothing. If in a group of 5 we all got involved equally, the teamwork would be very positive. Unfortunately, there is always someone who takes advantage of others' work.

I do not believe that MQs allow us to determine the degree of participation because each group has its own way of working. For example, in my group, we distributed the tasks, even if we did some things together.

Table 4.

Teammates	Project rating (1)	Individual MQs rating	Average MQs rating	Individual project rating
B1	9.3	9.3	6.7	8.9
B2	9.3	7.5	6.7	8.5
B3	9.3	5.6	6.7	8.2
B4	9.3	5.6	6.7	8.2
B5	9.3	5.6	6.7	8.2
C1	8.0	8.0	5.9	7.6
C2	8.0	7.3	5.9	7.5
C3	8.0	6.0	5.9	7.3
C4	8.0	6.0	5.9	7.3
C5	8.0	2.0	5.9	6.5
F1	6.7	6.7	5.3	6.4
F2	6.7	5.8	5.3	6.3
F3	6.7	5.1	5.3	6.2
F4	6.7	4.7	5.3	6.1
F5	6.7	4.2	5.3	6.0

(1) Top rating is 10

Table 5.

Teammates	Project rating (1)	Weight factor 1 (WF1)	Individual project rating
B1	9.3	1.4	13.0
B2	9.3	1.1	10.5
B3	9.3	0.8	7.8
B4	9.3	0.8	7.8
B5	9.3	0.8	7.8
C1	8.0	1.4	10.9
C2	8.0	1.2	9.9
C3	8.0	1.0	8.2
C4	8.0	1.0	8.2
C5	8.0	0.3	2.7
F1	6.7	1.3	8.5
F2	6.7	1.1	7.3
F3	6.7	1.0	6.4
F4	6.7	0.9	5.9
F5	6.7	0.8	5.3

(1) Top rating is 10

Table 6.

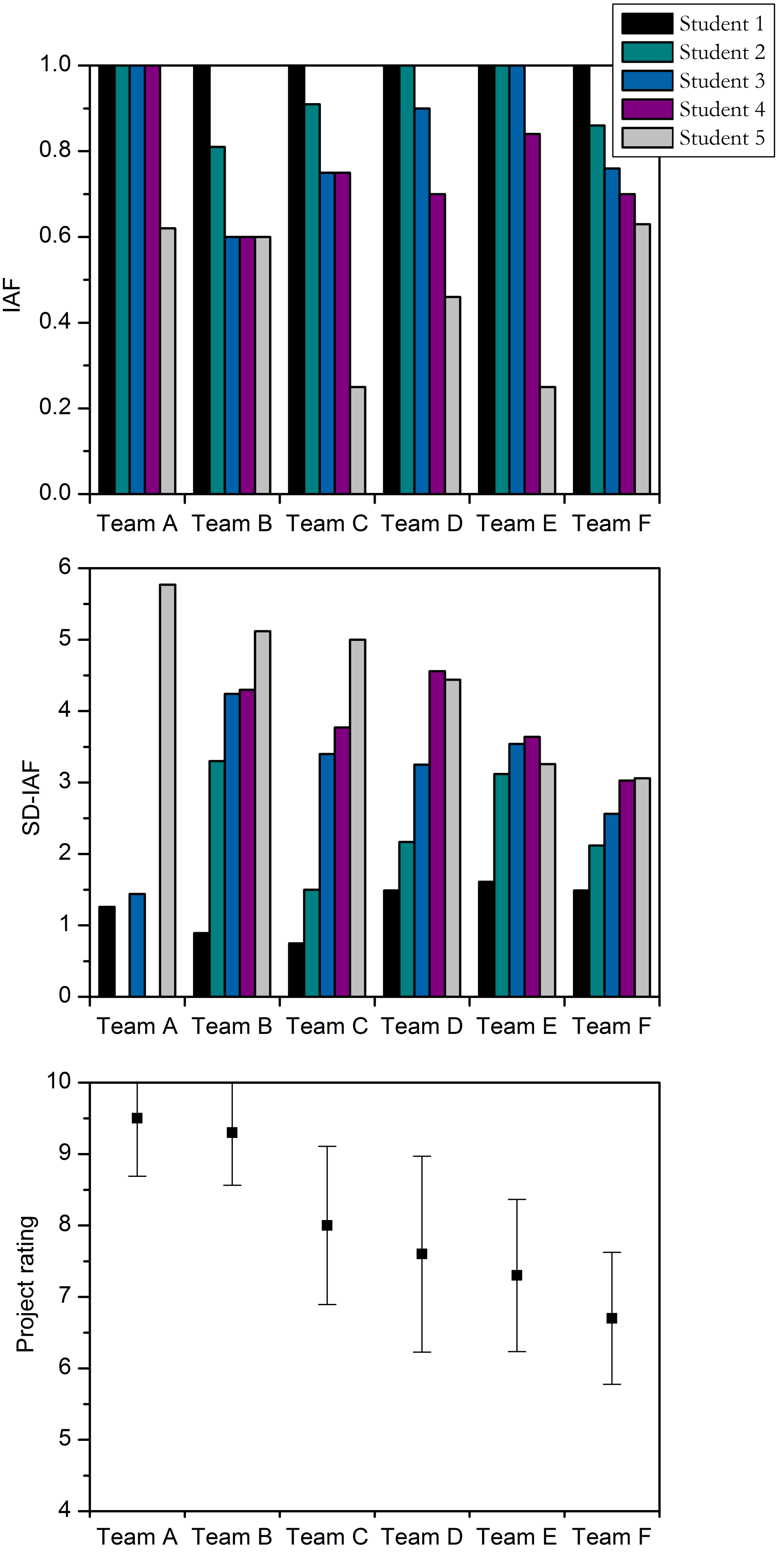
Teammates	Project rating (1)	Weight factor 2 (WF2)	Individual project rating
B1	9.3	1.0	9.3
B2	9.3	0.8	7.5
B3	9.3	0.6	5.6
B4	9.3	0.6	5.6
B5	9.3	0.6	5.6
C1	8.0	1.0	8.0
C2	8.0	0.9	7.3
C3	8.0	0.8	6.0
C4	8.0	0.8	6.0
C5	8.0	0.3	2.0
F1	6.7	1.0	6.7
F2	6.7	0.9	5.8
F3	6.7	0.8	5.1
F4	6.7	0.7	4.7
F5	6.7	0.6	4.2

(1) Top rating is 10

Table 7.

Teammates	Project rating (1)	Weight factor 3 (WF3)	Individual project rating
B1	9.3	1.2	11.0
B2	9.3	0.9	8.9
B3	9.3	0.7	6.6
B4	9.3	0.7	6.6
B5	9.3	0.7	6.6
C1	8.0	1.2	9.4
C2	8.0	1.1	8.6
C3	8.0	0.9	7.1
C4	8.0	0.9	7.1
C5	8.0	0.3	2.4
F1	6.7	1.2	7.9
F2	6.7	1.0	6.8
F3	6.7	0.9	6.0
F4	6.7	0.8	5.5
F5	6.7	0.7	5.0

(1) Top rating is 10


Student 1
Student 2
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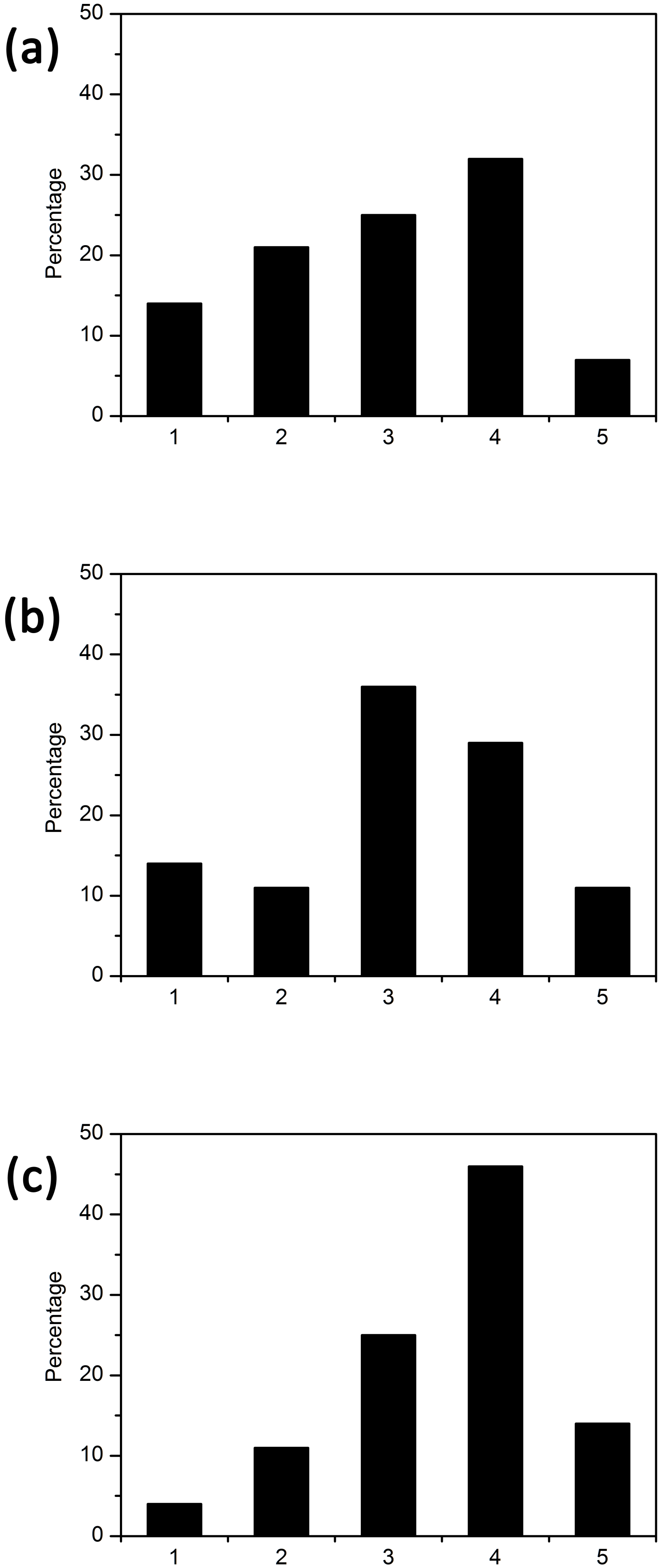
Student 4
Student 5
IAF
SD-IAF
Project rating
Team A
Team B
Team C
Team D
Team E
Team F



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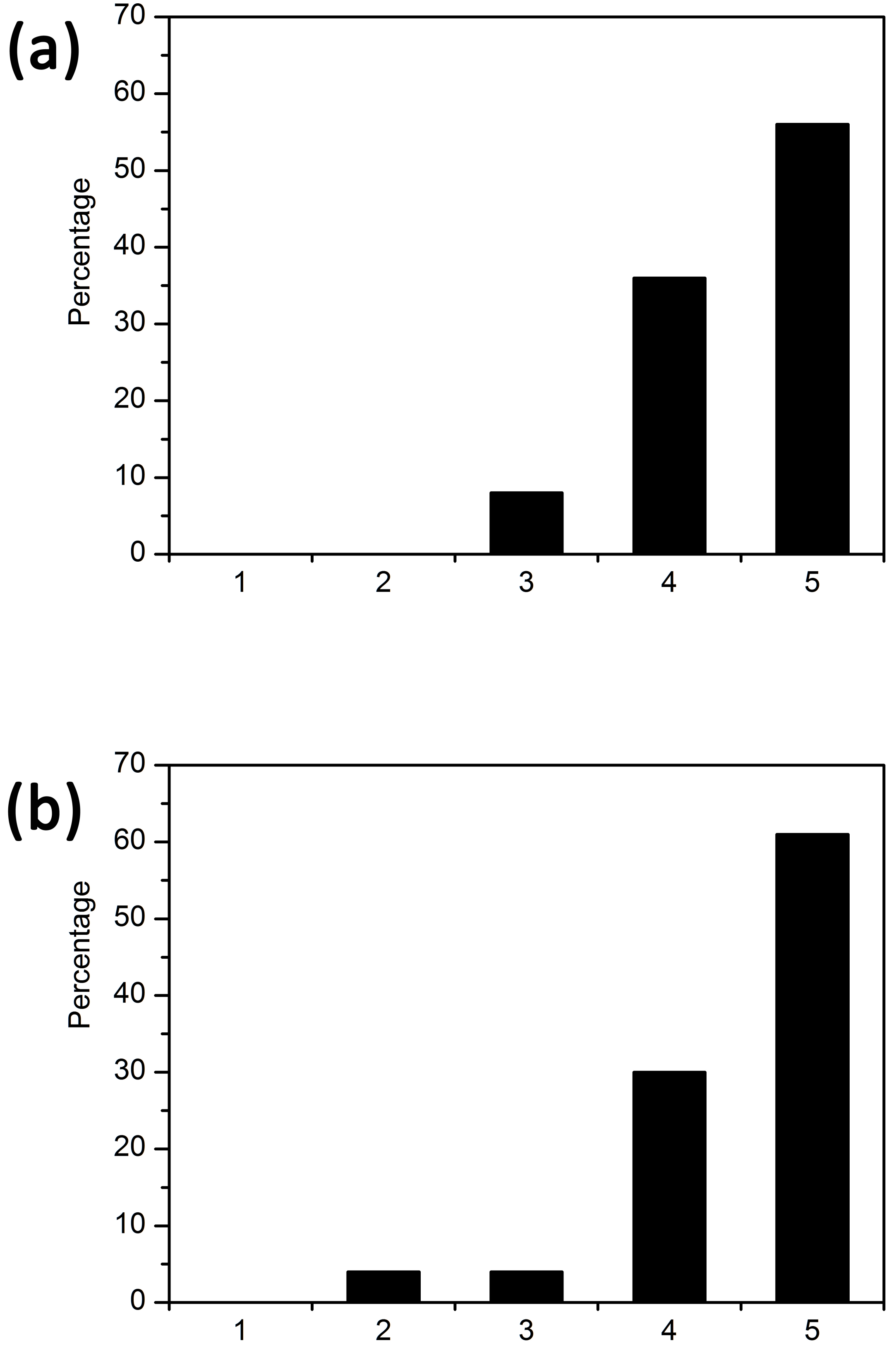
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SUPPLEMENTARY MATERIAL

RUBRICS FOR THE ASSESSMENT OF THE 5 DELIVERABLES OF A CHEMICAL PROCESS DESIGN PROJECT

Project example: “Direct Aromatization of Methane to Aromatics: DMA process”.

The set of criteria used in the rubrics is grouped into three sections: 1) Conceptual Content, 2) Written Communication and Format and 3) Meeting Minutes. The relative weight of each section is 70, 25 and 5%, respectively. The criteria used in Sections 2 (Table S1) and 3 (Table S2) are the same for each deliverable, while the set of criteria of Section 1 (Tables S3-S8) are specific for each milestone or deliverable. The criteria in Section 2 (Table S2) are the same as those used to assess Written Communication and Format in the Bachelor Final Project. Each criterion is classified into five levels of performance: absent (0 points), deficient (1 point), partially proficient (3 points) and proficient (5 points). The final score out of 10 is calculated by summing the weighted criteria scores (multiplying the weight by the performance score) and dividing by 5/10.

Table S1. Rubric for the assessment of written communication and format.

Criterion	Weight	Proficient (5)	Partially proficient (3)	Unsatisfactory (1)	Absent (0)
Clarity and correctness of language	7.50%	Academic language is used. Ideas are clearly and efficiently expressed. There are no syntactic and orthographic errors.	Academic language is not used but it is well-written. Ideas can be expressed more clearly. There are few syntactic and orthographic errors.	Colloquial language is used. It is not clearly written and there are incomprehensible sentences. There are major syntactic and orthographic errors.	Poor quality. Words and sentences are not completed. There are lot of major syntactic and orthographic errors. Unacceptable at university level.
Structure of the report	3.75%	Well structured text. Sections are properly separated.	Quite well structured text, but it can be improved.	Text structure is not appropriated to this report. Information is not adequately placed.	Text structure is not appropriated to this report. Incoherent times are included. Information is not properly placed. Unacceptable.
References	3.75%	References are written according to Bachelor Final Project format. There is no error.	References are written according to Bachelor Final Project format. There are few errors while citing references in the text.	References are not written according to Bachelor Final Project format. There are various errors while citing references in the text.	References are not included.
Figures, tables and equations	7.50%	Figures, tables and equations are written according to Bachelor Final Project guidelines. They are also properly cited in the text.	Figures, tables and equations are written according to Bachelor Final Project guidelines. It can be improved. There are few errors while citing them in the text.	Figures, tables and equations format is inappropriate: do not follow Bachelor Final Project guidelines, are not clear, do not have captions, titles...There are various errors while citing references in the text. Equation editor is not used.	Tables and figures are not used even if necessary. The format is inappropriate. Equation editor is not used and equations are not properly written. Unacceptable.
Report edition	2.50%	It is properly edited according to Final Project guidelines.	It is properly edited according to Final Project guidelines, but it has few errors.	It is edited according to Final Project guidelines, but it has several errors.	It is not edited according to Final Project guidelines. Unacceptable

Table S2. Rubric for the assessment of meeting minutes

Criterion	Weight	Proficient (5)	Partially proficient (3)	Unsatisfactory (1)	Absent (0)
Meeting minutes	5%	Meeting minutes are recorded adequately. Meetings are held regularly. Participants are collected in the minute. Next meeting objectives and date are fixed. Next task for each participant is determined. The executive role of each one is recorded and it is rotating.	Meeting minutes are recorded. Only one meeting is held. One of these points is not recorded in the meeting minute: participants, meeting date, matters discussed in the meeting, next meeting date and objectives, next task for each participant. The executive role is not rotating.	Meeting minutes are recorded. Only one meeting is held. Most of these points are not recorded in the meeting minute: participants, meeting date, matters discussed in the meeting, next meeting date and objectives, next task for each participant. The executive role is not rotating.	Meeting minutes are not recorded.

Table S3. Rubric for the assessment of conceptual content of Deliverable 1: Literature Survey.

Criterion	Weight	Proficient (5)	Partially proficient (3)	Unsatisfactory (1)	Absent (0)
Benzene use and relevance; chemical industry market for benzene	10%	The use and relevance of benzene and its market into chemical industry are perfectly explained.	The use and relevance of benzene and its market into chemical industry are well explained.	The use and relevance of benzene and its market into chemical industry are poorly explained.	The use and relevance of benzene are not explained and its market into chemical industry is poorly explained.
Two possible strategies for obtaining benzene from methane	15%	Two possible strategies for obtaining benzene from methane are presented. The difference between two processes is clearly explained and advantages and disadvantages of each one are identified. Besides, design difficulties are identified.	It is not extensively explained but all these aspects are covered: two possible strategies, the difference between two processes, advantages and disadvantages. Besides, design difficulties are identified.	One possible strategy for obtaining benzene from methane is presented. Besides, design difficulties are identified.	Possible processes are not presented.
Selection of best operating conditions for direct aromatization	10%	The best operating conditions for direct aromatization are selected (catalyst, temperature, pressure, conversion, selectivity…). All operating conditions required for simulation are included.	Most operating conditions for direct aromatization are selected.	Some operating conditions for direct aromatization are selected.	Operating conditions for direct aromatization are not selected.
Gross profit calculation	20%	Raw material and product prices are well defined. The source is identified. Gross profit is well calculated.	Raw material and product prices are defined (but not all of them are properly defined). The source is not identified. Gross profit is calculated but there are some errors.	Gross profit is not calculated. Most of the raw material and product prices are not properly defined.	Gross profit is not calculated and information is not included.
Process Concept Diagram	15%	Process concept diagram is perfectly done.	There are some mistakes in the process concept diagram presented.	Process concept diagram is not well done.	The process concept diagram is not included.

Table S4. Rubric for the assessment of the conceptual content of Deliverable 2: Reactor Design and Simulation

Criterion	Weight	Proficient (5)	Partially proficient (3)	Unsatisfactory (1)	Absent (0)
Reactor operating conditions	10%	Suitable operating conditions are provided based on the literature (journals, patents, encyclopedia): stoichiometry, conversion, side reactions, selectivity, P, T, phase, products and catalysts.	Most of the aspects related to the operating conditions based on the literature are provided	Few aspects related to the operating conditions are provided, and/or the literature references used are not specific or reliable.	Reaction operating conditions related to the process are not provided.
Reactor Simulation in PRO II.	20%	The simulation of the reactor has been correctly developed based on the reaction operating conditions defined above. The type of the reactor and the specifications have been correctly selected. Simulation File has been included.	The simulation of the reactor has been developed but it has some mistakes: the type of the reactor or operating conditions or specifications. Simulation File has been included.	The simulation of the reactor shows several mistakes and does not fulfill all the conditions. Simulation File has not been included.	The simulation of the reactor has not been performed.
Process Block Flow Diagram (BFD)	10%	The process BFD includes the main aspects and is correct.	The process BFD includes the mains aspects, but it shows some mistakes.	The process BFD shows several mistakes.	Process BFD is not included or it is unacceptable.
Flow Summary Table	10%	The information of the Flow Summary Table is well specified and correct/coherent based on the information proposed by Turton et al. (2013).	The information of the Flow Summary Table is well specified, but it shows some mistakes.	The Flow Summary Table shows several mistakes or is incomplete.	The Flow Summary Table is not included or it is unacceptable.
Reactor design (sizing)	10%	Reactor volume and its dimensions (L and D) have been correctly calculated. The criteria (heuristics, etc.) used for the design are well reported.	Reactor volume and its dimensions (L and D) have been correctly calculated, but with some mistakes or the criteria (heuristics, etc.) used for the design is incomplete.	Reactor volume and its dimensions (L and D) have been calculated with several mistakes. The criteria (heuristics, etc.) used for the design is incomplete or unacceptable.	The reactor design is not included or it is unacceptable.
Discussion	10%	Discussion of the results and main conclusions obtained are fully and well reported.	Discussion of the results and main conclusions are partially reported.	Discussion of the results and main conclusions are scarcely reported.	Discussion of the results and main conclusions are not reported.

Table S5. Rubric for the assessment of the conceptual content of Deliverable 3: Separation Processes-Process Overall Design.

Criterion	Weight	Proficient (5)	Partially proficient (3)	Unsatisfactory (1)	Absent (0)
Separation Train synthesis	10%	The criteria used for the selection of separation methods and equipment are appropriate and it is well reported. The separation train synthesis is well designed.	The criteria used for the selection of separation methods and equipment are appropriate and it is well reported to some extent, and/or the separation train synthesis is well designed, but it has some mistakes.	The criteria used for the selection of separation methods and equipment are not appropriate and it is scarcely reported, and/or the separation train synthesis shows big mistakes.	Both criteria and the separation train synthesis are incorrect and/or unacceptable.
Operating conditions	10%	Suitable operating conditions to be used in each unit (T, P and phases) are selected. Their election is well reported and justified.	Most of the suitable operating conditions to be used in each unit (T, P and phases.) are selected. Their election is partially reported and justified.	Few operating conditions to be used in each unit (T, P and phases) are selected. Their election is scarcely reported and justified.	The operating conditions to be used in each unit (T, P and phases) are incorrect or not included. And/or their election is not reported and justified.
Adjusting T, P and phase between operations	10%	T, P and phases of all the process streams between two separation processes have been adjusted correctly by using suitable equipment (pumps, compressors, heat exchangers, etc.)	T, P and phases of most streams between two separation processes have been adjusted correctly by using suitable equipment showing some mistakes.	Only the T, P and phases of some streams between two separation processes have been adjusted correctly by using suitable equipment showing several mistakes.	T, P and phases of the streams between two separation processes have not been adjusted.
Process simulation	10%	The simulation in PRO II is correct and includes all the separation units as well as feed purification and recycling. Unit specifications are well defined. Simulation File is included.	The simulation in PRO II is almost correct (few mistakes) and includes all the separation units as well as feed purification and recycling. Unit specifications are partially defined. Simulation File is included.	The simulation in PRO II shows several mistakes and includes some separation units, or feed purification and recycling are missing. Unit specifications are not well defined. Simulation File is not included.	The simulation in PRO II is unacceptable or it is not included in the report.
Process Flow Diagram (PFD)	10%	The PFD has been designed in VISIO or similar software and includes the main aspects reported by Turton et al. (2013): streams numbered, equipments description, etc. The information is correct.	The PFD has been designed in VISIO or similar software and includes some of the main aspects reported by Turton et al. (2013): streams numbered, equipments description, etc. and/or the information is partially correct.	The PFD has been designed in VISIO or similar software and includes few aspects reported by Turton et al. (2013): streams numbered, equipments description, etc. and/or the information is partially correct.	The PFD is not included in the report or the format is unacceptable.
Flow Summary Table	10%	The information of the Flow Summary Table is well specified and correct/coherent based on the information proposed by Turton et al. (2013).	The information of the Flow Summary Table is well specified but it shows some mistakes.	The Flow Summary Table shows several mistakes or is incomplete.	The Flow Summary Table is not included or it is unacceptable.
Discussion based on heuristics	10%	Discussion of the results (based on heuristics by Turton et al. (2013) and Seider et al. (2010) and the main conclusions obtained are fully and well reported.	Discussion of the results and main conclusions are partially reported.	Discussion of the results and main conclusions are scarcely reported.	Discussion of the results and main conclusions are not reported.

Table S6. Rubric for the assessment of the conceptual content of Deliverable 4: Heat Integration/Heat Exchanger Network Design.

Criterion	Weight	Proficient (5)	Partially proficient (3)	Unsatisfactory (1)	Absent (0)
Identifying hot and cold streams	3%	All the cold and hot process streams have been correctly identified.	Most of the cold and hot process streams have been identified.	Only a few cold and hot process streams have been identified.	Cold and hot process streams have not been identified.
Determining Pinch Temperature and minimum utility requirements	10%	Pinch temperature and the minimum utility requirements have been determined properly.		Pinch temperature and the minimum utility requirements have not been determined properly.	Pinch temperature and minimum utility requirements are not reported.
Estimating minimum number of heat exchangers	5%	The calculation of the minimum number of heat exchangers above and below Pinch is correct.		The calculation of the minimum number of heat exchangers above and below Pinch is incorrect.	The calculation of the minimum number of heat exchangers is not reported.
Heat exchanger network Design	22%	The network has been well designed above and below the Pinch.	The network has been well designed above and below the Pinch, but it has few mistakes.	The network has not been designed properly above or/and below the Pinch and it shows several mistakes.	The network is not reported.
Equipment Summary Table (only Heat Exchangers)	5%	The equipment summary corresponding to heat exchangers is well reported: area, U coefficient, Tin, Tout.	The equipment summary corresponding to heat exchangers is well reported but it shows some mistakes: area, U coefficient, Tin, Tout.	The equipment summary corresponding to heat exchangers is not well reported and it shows several mistakes: area, U coefficient, Tin, Tout.	The equipment summary has not been included in the report.
Estimating Hot and cold utilities, Utility Stream Table	5%	Both cold and hot utilities are correctly identified (water, steam, etc.) and the flowrate has been included in the Utility Stream Table.	Both cold and hot utilities are identified (water, steam, etc.) to some extent, and/or the flowrate has been included in the Utility Stream Table, but with some mistakes in calculation.	Only few cold and hot utilities are properly identified (water, steam, etc.) and/or the flowrate has been included in the Utility Stream Table, but with several mistakes.	There is no report of utility stream table or hot and cold utilities definition.
Process simulation	10%	Process simulation in PRO II after heat integration is correct. Unit specifications are well defined. Simulation File is included.	Process simulation in PRO II after heat integration is almost correct. Unit specifications are well defined, but with few mistakes. Simulation File is included.	Process simulation in PRO II after heat integration is incorrect, showing several mistakes. Unit specifications are not well defined. Simulation File is included.	Process simulation in PRO II after heat integration is unacceptable or it is not included in the report.
Process Flow Diagram (PFD) after Heat Integration	5%	The PFD after heat integration has been designed in VISIO or similar software and includes the main aspects reported by Turton et al. (2013): streams numbered, equipment description, utilities, etc. The information is correct.	The PFD after heat integration has been designed in VISIO or similar software some of the main aspects reported by Turton et al. (2013): streams numbered, equipment description, etc. and/or the information is partially correct.	The PFD after heat integration has been designed in VISIO or similar software and includes only few aspects reported by Turton et al. (2013): streams numbered, equipment description, etc. and/or the information is partially correct.	The new PFD is not included in the report or the format is unacceptable.
Flow Summary Table after Heat Integration	5%	The information of the Flow Summary Table is well specified and correct/coherent based on the information proposed by Turton et al. (2013).	The information of the Flow Summary Table is well specified but it shows some mistakes.	The Flow Summary Table shows several mistakes or is incomplete.	The Flow Summary Table is not included or it is unacceptable.

Table S7. Rubric for the assessment of the conceptual content of Deliverable 5: Final report (incl. Economic/Profitability Analysis).

Criterion	Weight	Proficient (5)	Partially proficient (3)	Unsatisfactory (1)	Absent (0)
Letter of Transmittal, Title page, Table of contents, Abstract and Introduction	5%	All these aspects are included: letter of transmittal, title page, table of contents, abstract (15 lines). The introduction includes a full review of the state of the art of the process, with a comparison of the different technologies available.	Most of these aspects are included: letter of transmittal, title page, table of contents, abstract (15 lines). The introduction includes a review of the state of the art of the process, with a comparison of the different technologies available, which could be improved.	Only few of these aspects are included: letter of transmittal, title page, table of contents, abstract (15 lines). The introduction includes a review of the state of the art of the process, with a comparison of the different technologies available, which could be greatly improved.	The following aspects are not included: letter of transmittal, title page, table of contents, abstract (15 lines). or their information or format is unacceptable.
Process Flow Diagram (PFD)	5%	The PFD has been designed in VISIO or similar software and includes the main aspects reported by Turton et al. (2013): streams numbered, equipments description, etc. The information is correct.	The PFD has been designed in VISIO or similar software and includes some of the main aspects reported by Turton et al. (2013): streams numbered, equipments description, etc. and/or the information is partially correct.	The PFD has been designed in VISIO or similar software and includes few aspects reported by Turton et al. (2013): streams numbered, equipments description, etc. and/or the information is partially correct.	The PFD is not included in the report or the format is unacceptable.
Flow Summary Table	5%	The information of the Flow Summary Table is well specified and correct/coherent based on the information proposed by Turton et al. (2013).	The information of the Flow Summary Table is well specified but it shows some mistakes.	The Flow Summary Table shows several mistakes or is incomplete.	The Flow Summary Table is not included or it is unacceptable.
Process Description	10%	PFD is correctly described referring to all the steps and units included in the process describing their main purpose.	PFD is described to some extent, referring to most of the steps and units included in the process describing their main purpose.	PFD is partially described and so are the steps and units included in the process.	The description of the PFD is not included in the report or it is unacceptable.
Utility Summary Table	5%	The Utility Summary Table is well described including the type of utility and its flow rate.	The Utility Summary Table is described including the type of utility and its flow rate, but it has few mistakes.	The Utility Summary Table is described to some extent, including the type of utility and its flow rate, but it has several mistakes.	The Utility Summary Table is not reported or the information and its format is unacceptable.
Equipment Summary Table	5%	All the equipments are described in detail: name, design parameters, material of construction, streams and operating P and T. The information is correct.	Most of the equipments are described in detail: name, design parameters, material of construction, streams and operating P and T. The information is correct with few mistakes.	Only few equipments are described in detail: name, design parameters, material of construction, streams and operating P and T. and/or the information is partially correct.	The equipment summary table is not included in the report or the content is unacceptable.
Estimation of Capital Costs and Manufacturing Costs	15%	The estimation of capital and manufacturing costs is correct and updated (CEPCI)	The estimation of capital and manufacturing costs is almost correct and/or not updated (CEPCI)	The estimation of capital and manufacturing costs is partially correct and/or not updated (CEPCI)	The estimation of capital and manufacturing costs is unacceptable or not included in the report.
Profitability Analysis	15%	The profitability analysis is well reported including cash flow diagrams and nondiscounted/discounted criteria. The information is correct.	The profitability analysis is well reported including cash flow diagrams and most nondiscounted/discounted criteria. The information has some mistakes.	The profitability analysis is partially reported including cash flow diagrams and nondiscounted/discounted criteria. The information has several mistakes.	The profitability analysis is not included or/and the information is unacceptable.
Discussion, Conclusions and Recommendations	5%	The main conclusions of the design study are presented with a clear statement of the recommendation, accompanied by justifications.	Some of the main conclusions of the design study are presented with a clear statement of the recommendation, accompanied by justifications.	Only a few conclusions of the design study are presented with a clear statement of the recommendation, accompanied by justifications.	No discussion, conclusions and recommendation section is included in the report or the information is unacceptable.