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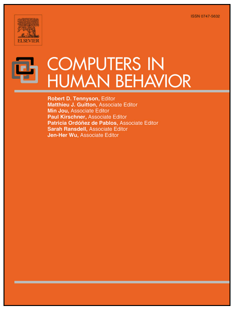

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A Collaborative Working Model for Enhancing the Learning Process of Science & Engineering Students

Higinio Mora[1], María Teresa Signes-Pont[1], Andrés Fuster-Guilló[1], María L. Pertegal-Felices[2]

[1] Department of Computer Technology and Computation, University of Alicante, Campus de San Vicente del Raspeig, 03690 Alicante, Spain. E-mail: *{hmora, teresa, fuster}@dtic.ua.es*
[2] Developmental and Educational Psychology Department, University of Alicante, Campus de San Vicente del Raspeig, 03690 Alicante, Spain. E-mail: *ml.pertegal@ua.es*

Corresponding author:
Higinio Mora
hmora@ua.es
Carretera San Vicente del Raspeig s/n
03690, San Vicente del Raspeig – Alicante
Spain.
Tlf: (+34) 96 590 3400 - Fax (+34) 96 590 3464

Abstract.-

Science and engineering education are mostly based on content assimilation and development of skills. However, to adequately prepare students for today's world, it is also necessary to stimulate critical thinking and make them reflect on how to improve current practices using new tools and technologies. In this line, the main motivation of this research consists in exploring ways supported by technology to enhance the learning process of students and to better prepare them to face the challenges of today's world. To this end, the purpose of this work is to design an innovative learning project based on collaborative work among students, and research its impact in achieving better learning outcomes, generating of collective intelligence and further motivation. The proposed collaborative working model is based on peer review assessment methodology implemented through a learning web-platform. Thus, students were encouraged to peer review their classmates' works. They had to make comments, suggest improvements, and assess final assignments. Teaching staff managed and supervised the whole process. Students were selected from computer science engineering at the University of Alicante (Spain). Results suggested greater content assimilation and enhanced learning in several scientific skills. The students' final grade exceeded what any student could produce individually, but we cannot conclude that real collective intelligence was generated. Learning methodologies based on the possibilities of Information and Communication Technologies (ICT) provide new ways to transmit and manage knowledge in higher education. Collaborating in peer assessment enhances the students' motivation and promotes the active learning. In addition, this method can be very helpful and time saving for instructors in the management of large groups.

Keywords.- *Higher Education; ICT Learning Technologies; Quality Assessments; Computers in Human Behavior; Collaborative learning; Student experiences; collective intelligence*

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1. Introduction

Pace of change is fast in our world. Our information & knowledge society demands new ways to transmit and manage knowledge. Higher education is seeking to address these challenges at the international, national and institutional levels. Curricular reforms should lead to high quality, flexible and lifelong education. The European *Bologna Process* (EURASHE, 2009; Zahavi, 2019) drives new teaching-learning approaches based on student-centred models which are more active and connected to real life. They should guide higher-education graduates towards greater adaptability to change by means of constant knowledge update and course adjustments. In such a way, future professionals don't stop learning after university. They need to be engaged in their own education throughout their life.

In this way, future-education implies more than just content assimilation. It involves the mobilisation of knowledge, new skills, attitudes and other values to meet complex demands (OECD, 2018b). Due to increasing competitiveness and a changing industrial environment, adaptability and creativity is even more crucial to learn to seize opportunities that can arise especially in the context of research, technology development and industrial engagement (Egan *et al.*, 2017; Juhl and Buch, 2019).

Recent studies indicate that higher education still plays a minor role in innovation (OECD, 2017b). Moreover, this is a process that needs knowledge production and, above all, using it in the right way to resolve our current challenges (Silvestre and Ţîrcă, 2019). Governments and public administrations want education systems to be more relevant to the needs of society and industry. Although the shape of future labour market needs is uncertain and depends on numerous factors which are difficult to predict (OECD, 2010; Lloret□Climent *et al.*, 2018), it is a fact that there are not enough qualified people to fill increasing numbers of jobs related to new technologies and social change that is taking place all over the globe. In this way, most demanding knowledge and skills are in new technology areas (Petrone, 2019). Disruptive technologies are changing the world and new skills need to be added to education curriculums to make the best use of their possibilities (Mora *et al.*, 2018; OECD, 2018a). Students not only need to be well-trained in knowledge and skills appropriate to their area, but also they should be creative in their proposals to provide valuable and disruptive solutions in a changing environment. New teaching-learning approaches are required; they must be more active and connected to real life, they should guide higher-education graduates to more capability of adaptation to variable circumstances by means of constant knowledge revision and course-correcting.

It is not easy to identify the skills required for innovation, creativity and entrepreneurship, and for enabling students to better exploit the new technologies capabilities (Keinänen and Kairisto-Mertanen, 2019).

Recent recommendations by IEEE and ACM (IEEE & ACM, 2016) propose a solid foundation in technical skills, in-depth knowledge of technology, and other valuable behavioural and academic skills beyond contents. These include leadership and collaboration, oral and written communication skills, project -based learning and design thinking (Dias and Soares, 2018) as well as analytical and critical thinking. Other reports stress the importance of adaptative education policies and promoting collaboration between employers and high education institutions in order to match emerging labour market needs (OECD, 2017a).

These abilities are especially important to address in the academic curricula of Information and Communication Technology (ICT) so that engineering graduates learn to exploit opportunities created by technological innovation.

These issues **motivate** our current research: taking up the challenge, we propose a learning methodology aimed at placing students in a better position to compete in a global world. Thus, the **aim of this work** is to help engineering students acquire new capabilities. Our objectives focus on educating students in the following areas: (i) new ways to access knowledge, (ii) collaborative learning, and (iii) developing critical thinking. Consequently, **expected results** obtained from the proposed methodology are mainly the understanding and application of the scientific method, a higher standard in end assignments, enhanced access to knowledge, and the production of collective intelligence instead of multiple individual intelligences. The concept of 'collective intelligence' refers to the contribution of collaborative efforts of members of a group to the global intelligence and outcomes (Jeng and Huang, 2018).

It is especially important to exploit collective intelligence in the field of engineering, because it helps students increase their potential and achieve more creative technological solutions in answer to the significant challenges in society. These students not only have technological competences linked to new knowledge, but they also need to acquire competences linked to new ways to access and use knowledge (Meza et al., 2016). Moreover, practicing the scientific method leads to greater rigor in the writing style and a capacity to understand scientific and technical documents. These are very important skills for engineering students.

The way in which these results are obtained is described and discussed in this work. The **basic idea** consists in implementing a blind-review of classroom assignments by students themselves. This means that students review the work of other students in a collaborative way. Thus, the results achieved are consequence of collaborative work of the author and the reviewers, who propose suggestions and changes to improve the final work. Collective intelligence can arise from the student's collaboration in solving the same issue.

To properly implement the method in an educational environment, an interactive web platform able to handle a large amount of students is required. The design of a web-based environment as a collaborative platform where users can share information and take advantage of the interactions of other users to enhance their own experiences has come to be known as Web 2.0 (Mata et al., 2019; Lytras and Ordonez, 2009). This web paradigm allows developing user-centred applications sharing the common characteristic of being more interactive and participative.

The **main contribution** of this work is the classroom implementation of a review process to assess academic work with the aim of evaluating whether this proposed review process is efficient in developing engineering student capabilities as referred to above. The research framework basically consists in implementing a case study in a subject of the Computer Engineering Degree at the University of Alicante. Within this framework, we have defined several variables of interest to be analysed and three research questions. They have been selected and designed according the specific aims of this work.

The **novelty** of this work lies in using the review process as a teaching/learning methodology to address interesting open academic issues such us how access to knowledge can be improved, how critical thinking can be developed, and when and where collective intelligence emerges. The analysis conducted and the answers provided was mainly qualitative since most of the improvements achieved come from personal insights of the outcomes and require a qualitative analysis.

First, we describe previous research on peer reviewing, we summarise findings and formulate our research questions; second, we introduce different aspects of the collaborative assessment model. We then present a case study to show how our method unfolded and the results obtained. Finally, we draw conclusions on the answers to our research questions obtained and the main advantages and limitations of this methodology.

2. Related work

We review below a selection of recent and significant literature allowing us to illustrate the intensity and diversity of research in the field. A final subsection is added, summarising contributions to this study.

2.1. Peer Review in Education

Peer review is a method for verifying ideas and conclusions presented in research papers (Masic, 2016). Subject matter experts carry out the peer-review process (there are usually two reviewers per article) by writing their opinion on the research work. This process consists in analysing different aspects, such as whether the research was well designed and executed, whether the description of the method makes it reproducible, whether data are unambiguous and properly analysed, and whether conclusions are supported by data (PNAS, 2016).

As a result, authors obtain valuable feedback on the novelty and added-value of their work, the methodology used, and their contribution to the scientific community. This method is not perfect, but it is "*the least worst*" system we have for verifying ideas and conclusions in research publications (Smith, 2006). Therefore, the critical review of work by peers is an interesting exercise that offers engineering students desirable skills in line with the aim of this work (Song et al., 2016; Tenório et al., 2016). In this way, student peer review increases students' participation and fosters collaborative learning. This collaborative learning is produced when students collectively work towards a common academic goal (Kotsopoulos, 2010). Thus, it is already used in higher education as a pedagogical methodology for several purposes. There are two main aims for using peer review as an academic tool: (i) to improve learning, and (ii) as an assessment tool for learners and teachers.

(i) The peer review method as a means of improving learning has been implemented in several studies in science and engineering education courses. Results show that, in general, participating students improve their skills at critical-reading and writing (Zwicky and Hands, 2016; Lai and Hwang, 2014; Tenório et al., 2016), and enhance other academic skills such as their achievement in complex cognitive tasks, development of professional behaviour and social interaction (González-Marcos et al., 2018).

(ii) From this point of view, peer assessments by students are an effective way to help them examine their learning progress, develop personal autonomy and increase learning motivation (Wen and Tsai, 2008). In this case, a greater volume of feedback is available than when relying only on teacher feedback and a broader variety of opinions are provided on the work (Topping, 2009). However, the validity of peer assessment scores given by students requires supervision and a training process (Verleger et al., 2016). Automatic tools have been designed to assess the quality of reviews by students (Yadav and Gehringer, 2016; Ramachandran and Gehringer, 2012). This process may improve the results and encourage to students as reviewers to better make their job. In addition, peer review method represents a valuable tool to handle courses where a large number of students are enrolled, as it saves teachers' time (Sadler and Good, 2006; Mora et al, 2009). Moreover, such students' review is easier to understand than instructors review and, therefore, easier to use in improving the works (Cho and MacArthur, 2010).

These purposes are complementary and they can be pursued by course designers simultaneously in order to implement formative assessment. The formative assessment has significant impact on student achievement (Andersson and Palm, 2017) and in generating learning feedback (Tempelaar et al., 2018). Thus, it is used to enhance the educational process and increase effectiveness of learning, especially in engineering subjects (Hassan, 2014). In addition, formative assessment creates a value-added learning process activating students as owners of their own learning among other positive aspects (Lyon et al., 2019).

Table 1 summarises main recent contributions in this area and their typical outcomes. Key results have been underlined. The results of these works show the potentials of using the peer-review method in education and provides the conceptual framework of this research.

Table 1
Representative works on Peer Review in Education

Main aim & works	**Key outcomes.**
Learning methodology	
Interactive learning through web-mediated peer review (Trautmann, 2009). Science students, University in Pennsylvania, USA.	<u>Gains in scientific writing</u> of lab research reports.
An experiment and lessons learned in applying peer reviews (Garousi, 2010). Engineering students, University of Calgary, Canada	<u>Noticeable knowledge gains</u> in students with respect to preparing high-quality design documents and also being more effective in identifying defects.
Developing Technical Writing Skills (Gragson and Hagen, 2010). Science students, California Polytechnic State University, USA	<u>Improvement in the quality</u> of lab reports written by students.
The Effect of Peer Review on Information Literacy Outcomes (Zwicky and Hands, 2016). Science students, Purdue University, USA	<u>Improvement in meeting information</u> literacy outcomes and in assembling the results into a brief paper.
Peer Review System (Lundquist et al., 2013). Engineering students, Linköping University, Sweden	The <u>quality</u> of the student reports has <u>improved</u>.
Assessment tool	
Online peer assessment (Wen and Tsai, 2008). Science Teacher Education students, National Taiwan University of Science and Technology, Taiwan	Instructors' marks were not significantly correlated with peers' marks in all outcome variables. <u>Assessment needs more practice</u>.
Assessment process by students (Mora et al, 2009). Engineering students, University of Alicante, Spain	<u>Positive attitude</u> was shown among first-year students. Peer and instructor scores were increasingly in line along the course.
Peer Assessment (Topping, 2009). School of Education at the Universuty of Dundee, UK.	<u>Peer assessment requires training</u> and practice. It has been shown to be effective in a variety of contexts.
Automated metareviewing (Yadav and Gehringer, 2016). Departments of Engineering, Science and Business, NC State University, USA.	The <u>reviews can be automatically rated</u> to evaluate their usefulness and improving the quality of reviewing.
Analysis of peer, self, and tutor assessment (Papinczak et al., 2007). Medical students, University of Queensland, Australia	Students were better <u>able to accurately judge the performance of their peers</u> compared to their own performance.
Role of self-assessment (Keller, 2016). Hungarian Life Course Survey. Budapest, Hungary.	<u>Self-assessment provides a higher perception of one's own ability</u> and contributes to the choice of the optimal level of effort.
Impact of self-assessment (Sharma et al., 2016). Physiology students, Guru Gobind Singh Medical College, India.	<u>Self-assessment can increase the interest and motivation</u> level of students for the subjects leading to enhanced learning and better academic performance.
A systematic review of the literature (Tenório et al., 2016).	There are empirical evidences of the <u>benefits of peer assessment</u> in several educational levels.

Formative assessment	
Self- and Peer-Grading on Student Learning (Sadler and Good, 2006). Science students, Harvard University, USA.	Self-grading and peer-grading appear to be reasonable aids to saving teachers' time.
Formative and summative rubrics (Song et al., 2016). College of Engineering at NC State University. USA.	Combination of formative and summative rubrics produces higher reliability and increase helpfulness of review comments.
Impact of formative assessment on student achievement	
Peer Assessment Enhances Student Learning (Sun et al., 2015). Science students, Stanford University, USA.	Peer assessment causes a small but significant gain in student achievement.
Peer-learning and formative assessment (Hassan, 2014). Science students, Linköping University, Sweden	The formative assessment methodologies increase the effectiveness of learning in engineering education.
Academics' perceptions of peer assessment in higher education. (Adachi et al., 2018) Deakin University, Geelong, Australia	Describe benefits and challenges of self and peer assessment as formative assessment.
Peer assessment in university teaching (van den Berg et al., 2006). History students, University of Utrecht, Netherlands	Students positively appreciated the method of peer assessment. Reading and assessing fellow students' work was a useful activity
Computer-Assisted Method (González-Marcos et al., 2018). Engineering students, University of La Rioja. Spain.	Positive impact on the academic achievements of engineering students.

2.2. Collaborative technological tools for education

There are a lot of generic online platforms for performing the peer review process. In academic context, the tools may provide the appropriate items for peer review and help the work made by students. In this way, some items can be added to the application such as example contents, scoring rubric, and other helping documents. The online tools provide facilities to do the work more quickly and more flexibly, and allow a centralized management by instructors. Thus, they integrate the comments and marks, and both the work done by students and reviewers can be assessed in an efficient way. These comments can be used for instructors to assess the work by reviewers. In some cases, the methodology requires only modest instructor involvement and, therefore, a lot of teachers' time is saved [15].

The general usability such as layout, presentation, format, duration and difficulty are also an important issue for the academic tool [16]. Other aspects could be welcome for awakening the interest of the students. Thus, the design for mobile devices can enhance the peer-learning and reach a great collective of users. The ubiquitous access to the platform from anywhere and anytime facilitates the student involvement in the works [17]. Table 2 summarizes the representative technological tools for education.

Table 2. Peer Review tools for education

Work	**Main aim**	**Key Outcomes**
Intelligent Personalized e-Assessment Tool [23]	Development of a web-based evaluation system that adjusts to the level of knowledge of each student.	The adaptive evaluation framework proposed provides a more realistic assessment of the student's level of knowledge.
Computer-Mediated Peer Review [20]	Evaluation of efficacy of using CPR both for learning and for teaching engineering design.	The tool gives faculty and students the ability to analyze the process of instructional activities. This increases the instructor's awareness of how students learn.
Teaching to Learn – TeatoL [24]	Create and evaluate a learning environment.	The students are embedded in a collaborative environment where all learn collectively from each other's experiences, even the instructors.
Web-based formative assessment tool [16]	Development and evaluation of an online formative assessment tool	The development of such tool is both appropriate and feasible for Master students.
Increase Student Confidence in Assessing Their Own Writing [18]	Evaluating the online writing software CPR for assigning writing assignments in large college classes.	CPR is a useful tool for assigning writing assignments in large college classes. The students become more confident in their ability to evaluate the quality of their own work.
Improving Engineering	Creating an enhanced version of	Students were able to calibrate and

Education [19]	CPR.	participate in online peer review of communication assignments while faculty encountered obstacles when attempting to integrate video components.
Mobile self- and peer-assessment system [21]	Development of a Mobile Assessment Participation System using Personal Digital Assistants	The proposal helps the teacher to arrange the assessment more flexibly and to make students more attentive to presentation, interaction, and feedback in the assessment process.
Formative assessment-based mobile learning approach [22]	Evaluation and development of a formative assessment-based approach in a mobile learning environment.	The proposed approach promotes the students' learning interest and attitude, and also improves their learning achievement.

2.2. Findings

Following our review of representative proposals in this field, we identify particular findings that justify and summarise our contributions to these previous works:

- Studies conducted on the peer review method in the teaching/learning process conclude that learning improvements take place. These enhance different and valuable skills especially in the case of science and engineering education. Moreover, this practice can increase motivation and interest in studying the subjects.
- Peer assessment among students can also benefit teachers and students when carried out thoughtfully. According to the in-depth meta-analysis conducted by Falchikov (Falchikov and Goldfinch, 2000), peer assessment provides greater validity in advanced rather than beginner courses and in science and engineering rather than in other disciplines.
- The online platforms have been proven valid tools for implementing the peer assessment process in educational environments. These platforms provide a way to implement Technology Enhanced Learning strategies in Higher Education in order to obtain better outcomes and engaging students in their own learning.

The peer review technique is not new in education. Nevertheless, current evolutions in technology offer new possibilities for communication, collaborative learning, searching for information, and other value-added tools and cloud-based services for engineering education. In this way, there is room for new approaches and improvements in student peer-review methodology.

2.3. Research questions

Our research aims at achieving outcomes similar to those described previously and, in addition, to leverage the potential of technological value-added tools. In this way, our research efforts focus on developing a constructive learning process based on collaborative work to outperform individual results in science and engineering skills such as the ability to design, willingness to learn and attention to detail. As a result, we attempted to answer the following research questions:

1. *How does the peer assessment activity increase engineers' final quality of work including problems, projects, designs and reports?*
2. *How is student behaviour regarding knowledge access improved by means of the peer review methodology?*
3. *Does the peer review methodology generate collective intelligence thanks to students' collaboration?*

3. Collaborative assessment model

3.1. Methodology

The methodology used in this work consists of an analytical qualitative process (Collins and Stockton, 2018) designed to find out how well is the collaborative peer-review method enhancing the teaching-learning process of science & engineering students. It is basically an inductive method where knowledge is created from data and human behavior observed and analyzed by experienced professionals in educational area. From the previous research questions, eight variables of interest have been defined grouped by several categories related to these questions.

The research questions require a qualitative analysis of the results because improvements achieved mainly come from personal insights of the outcomes made by the teaching staff involved in this research. This analysis can be characterised through phenomenology case study since it is one of the most flexible approaches to qualitative research and allows a detailed investigation of the development of the events in order to understand the experiences of participants and draw conclusions from it (Crawford, 2016; Mihas, 2019).

The case study has been designed to implement the peer review method in a real scenario within a group of students in their first year of their Computer Science Degree. Over this case study, the variables of interest have been studied in order to infer some findings by which we can answer the questions and make the conclusions. The first course was chosen to involve students in this methodology from the very beginning of their university studies. Continuous learning is very useful along the degree. In addition, engineers are required to update their knowledge all along their professional lives because of ongoing technological advances. Students generally have advanced technological skills from a user point of view (Mora et al., 2015), but they have significant shortcomings in professional and scientific methodologies.

The purpose of the study according the stated research questions is to discover any learning gains in access to knowledge, collaborative learning, and collective intelligence. In addition, the proposed method implements some of the recommendations given by the Bologna Process (EURASHE, 2009) such as student-centred, active learning and continuous assessment of students during the academic course.

This methodology can also be envisaged as a game, promoting the collaboration and involvement of students who act the part of teachers to engage them in the learning process. From this viewpoint, the methodology can be considered as having a motivational role (Bodnar et al., 2016).

The study was carried out over two consecutive academic years. Students under study were in their second year (group A). The control group was made up of students in their first year (group B) and was used to compare the results and draw the conclusions of this work. We avoided forming both study and control groups within the same year because of likely student complaints about not sharing the same assessment criteria and process. By using two different years, the evaluation methodology could be changed for all students without any interference. As a result, we were able to check whether collective intelligence arose from incremental and collaborative work.

3.2. Variables of interest

Peer assessment methodology can be organised in many different ways, so it is important to be explicit about the variables under study (Topping, 1998; van den Berg et al., 2006). Variables of interest to conduct our research and test the qualities of the method proposed in this work were selected as follow: assessment, bias, originality, quality, improvement, experience, collaboration, and criticism. Table 2 below lists the definition of each variable as interpreted in this study and conditions of obtention. Variables were categorised into four groups with different aims for this research. This can be considered as a framework for the design of the proposed peer review process for engineering students.

Table 2
Framework for the design of the proposed peer review process for engineering students.

Category – Research aims	Variable	Description
Assessment • Critical thinking development. • Time saving for instructors.	#1 assessment	Checking the validity of students' assessments and assess whether the comments made are clearly founded.
	#2 bias	Measuring the relation to staff assessment.
Information access • Learning to search information • Enhancing access to knowledge. • Learning to synthesize gathered information.	#3 originality	Finding out if the student's work is made up through copy and paste or it is own-elaborated from the sources.
	#4 sources	Assessing the type of sources used according to their rigor (web pages, proceedings, journals) as well as the language used (Spanish, English, other)
Quality of works • Incremental learning. • Continuous learning.	#5 improvement	Checking whether incremental and continuous learning is produced along the course.
	#6 experience	Finding out if the student learns from the reviewers' comments.
Collaborative learning • Development of collective intelligence.	#7 criticism	Assessing the review comments made by students.
	#8 collaboration	Assessing the collaboration of the reviewer to improve the final work.

The research framework is now developed based on the collaborative assessment model definition, the objectives of this research, the proposed research questions and the former set of variables grouped by category.

3.3. Collaborative process

Our proposal is based on a previous pilot study designed to encourage student engagement with difficult subjects (Mora, 2009). Based on that experience and results obtained, we improved and expanded the process to take into account new goals introduced in our work. As mentioned previously, the process was devised to last throughout the school year.

The basic idea was to reproduce, in the classroom, the same peer review process that is used in scientific journal publishing procedures. In addition, some new elements were introduced to enhance collaborative work and stimulate collective intelligence. Students were considered as authors and as reviewers at the same time: they were authors of their own work, and reviewers and collaborators of other students' work. Thus, teaching staff encouraged students to carry out reviews not only by merely applying rubrics, but also by proposing new ideas and improvements to the work they reviewed. The aim was that students themselves be able to provide useful feedback for improving work and projects without teacher intervention.

The assessment method began in the lecture hall, where the teacher explained to students how to begin the process, the necessary items and a tutorial on how to use the on-line web platform. For both study groups, several class assignments were planned along the course (one for each topic covered in the course). For the experimental group (group A), the first assignments were carried out applying the collaborative peer review process and the last one was done conventionally. This way it was possible to analyse and assess all variables of interest. The control group (group B) had to carry out the same work by following a standard teaching procedure consisting in explaining each assignment as well as the individual and independent work that was expected of them. For this latter group, the teaching staff was in charge of the whole assessment process and provided comments and grades to the students for each assignment.

Class assignments were designed to analyse the variables under study and to assess how efficient the collaboration method was. Each assignment was designed to assess a set of key aspects to obtain an estimation of the behaviour of the variables. Reviewers were randomly assigned and switched at each assignment. In this way, the teaching staff could obtain useful information about individual involvement and the quality of comments by comparing student reviews.

The instructors' explanations and the lecture note materials were the same for both groups. For group A only, teachers provided additional documents to properly perform the review process, and deal with general inquiries and questions on the assessment procedure. Documents provided by teaching staff are described in Table 3 below.

Table 3
Documents used in the collaborative review process.

Document	Description
Work definition	Common for both groups A and B. The teaching staff proposes exercises, problems or questions that must be answered by the students. They must apply the knowledge they have acquired by attending the lectures with the help of bibliographic references and additional information.
Peer review procedure	Only for group A. This document describes the procedure of peer review and the stages to go through.
Reviewer Scoring Rubric	Only for group A. This document sets out the criteria for undertaking the assessment work and allows a normalized scoring of all works. There are general criteria and specific ones for each type of work.
Author Response Template	Common for both groups A and B. This template is used by the authors to submit the review comments and describe how the reviewers' suggestions are taken into account and added to the work. This is also used to describe further improvements made to the new version of the work.
Author Valuation Template	Common for both groups A and B. This document allows authors to comment on the assessments and suggestions received. This document allows the teachers to be aware of the work made by reviewers and take corrective actions if necessary. For group B, teachers can receive the opinions of the students about their assessment.

3.4. Collective Intelligence

The development of complex solutions in today's global world requires the collaboration of many people. In this way, teamwork and cooperation towards higher achievements are very important skills for engineers and scientists. Experimental studies have pointed to the existence of collective intelligence when people work together (Hansen and Vaagen, 2016). Learning from others' activities and tasks is becoming ever more common in the digital society. Many digital platforms and web-based collaborative systems are dedicated to sharing knowledge and experiences in many areas (Al Omoush, 2018). The educational sector should take advantage of this phenomenon where collective intelligence can emerge from the collaboration and competition of many individuals. However, difficulties remain in determining where and how it takes place. Coordination costs seem to prevent advances in group problem-solving (Bates and Gupta, 2017).

In this work, we explore how intelligence can emerge from the review process since it involves working together towards improvement. There are a few important aspects in this process: interactions among students, constructive comments made, and feedback received by authors. Instructors aim at enhancing these aspects in this process. In addition, collaborating in learning and the possibility of anonymity in making comments may enable to overcome coordination issues and typical student shyness.

Any increase in intelligence may be measured by comparing the quality of final work executed with and without a previous review process.

3.5. Collaborative Platform

Online platforms have proven to be valid tools for implementing peer assessment processes in educational environments. In recent times, these tools have evolved and now incorporate specific features in the generic assessment function to make them more attractive for students and to implement different educational strategies.

The use of 2.0 features in the construction of educational platforms allows building collaborative strategies on them to improve the teaching-learning process (Grosseck, 2009). This development may lead to a new type of pedagogy based on collaboration and generation of collective intelligence among students. However, these platforms must be designed very carefully because of the risks involved. When students collaborate to construct knowledge, individual contributions and learning are not clearly detectable. Student assessment thus becomes a critical task when these tools are used in the teaching process.

In this work, a custom standard peer review platform was developed for this purpose. This platform was based on other well-known platforms for peer review such as *EasyChair* (http://easychair.org/) or *EDAS* (https://edas.info/doc/) used for scientific conference management. The design features of the platform are as follow: *Capable:* handles hundreds of works and supports several review rounds for each work; *Ubiquitous:* hosted in the cloud, the platform can be accessed at any place at any time; *Accessible*: prepared for different interfaces including mobile and desktop devices; *Effective*: capability to produce reports for each student with a summary of contributions for each assignment and each round, and finally *Usable*: Adapted for non-expert users.

An evolution of this platform based on a semantic web design is still under development. It is expected to build a knowledge corpus from collaborative comments to help students avoid common errors in preparing their work (Vargas-Vera and Lytras, 2008).

The email tool has also been used to send documents and messages from instructors to students and to receive comments directly from students on eventualities in the review process such as corrupt document notifications, deadline extension requests, etc.

4. Case Study

An empirical research has been carried out in order to know the impact of the collaborative assessment model in learning outcomes of students related to accessing to knowledge, collaborative learning, and collective intelligence generation. The methodology used is based on a case study. This is appropriate when researching "how" or "why" questions such as the research questions described previously, and it is especially suitable for studies in real-life contexts (Yin, 2013). In addition, case study is one of the most flexible approaches to qualitative research (Collins and Stockton, 2018). Indeed, new research questions can arise from the results.

The collaborative assessment model has been gradually improved and experimented in several subjects of the *Computer Engineering Degree* at the *University of Alicante*. In this study, we focus on our last experiment carried out on the subject of *Computer Architecture Foundations*. It is a basic subject with many students and therefore we can obtain meaningful data for this research.

The case-study was developed during two consecutive courses as follows: the first academic course 65 students were enrolled in the subject (2016/2017). This group (group B) uses the traditional assessment method made by instructors and was taken as control group. The following academic course new 78 students were enrolled (group A) in the same subject (2017/2018). In this group of the second year, the collaborative assessment model was implemented, and their results were analyzed. Over these two years, a total of 143 students were involved in this study (they are between 18 and 20 years old, 112 male and 21 female). All of them finished the courses.

There are not significant changes in this subject from a year to the next one. Indeed, we used the same bibliography, academic material and classworks on the same topics. Teaching staff was the same for both courses and was composed of 4 teachers with extensive experience and technical capacity in the area of computer science education (three of them are co-authors of this work). Teaching staff had planned four class assignments along the academic course (the subject under study was six-monthly). To conduct this research, the first three assignments had a different assessment methodology for groups A and B, and the fourth maintained a conventional methodology for both. For the first three classworks, the group A used the peer-review method while group B used the classical assessment by the instructor. The outcome of this case study is reported in the present paper.

Figure 1 shows an overview of the methodology and all the elements involved in this case study.

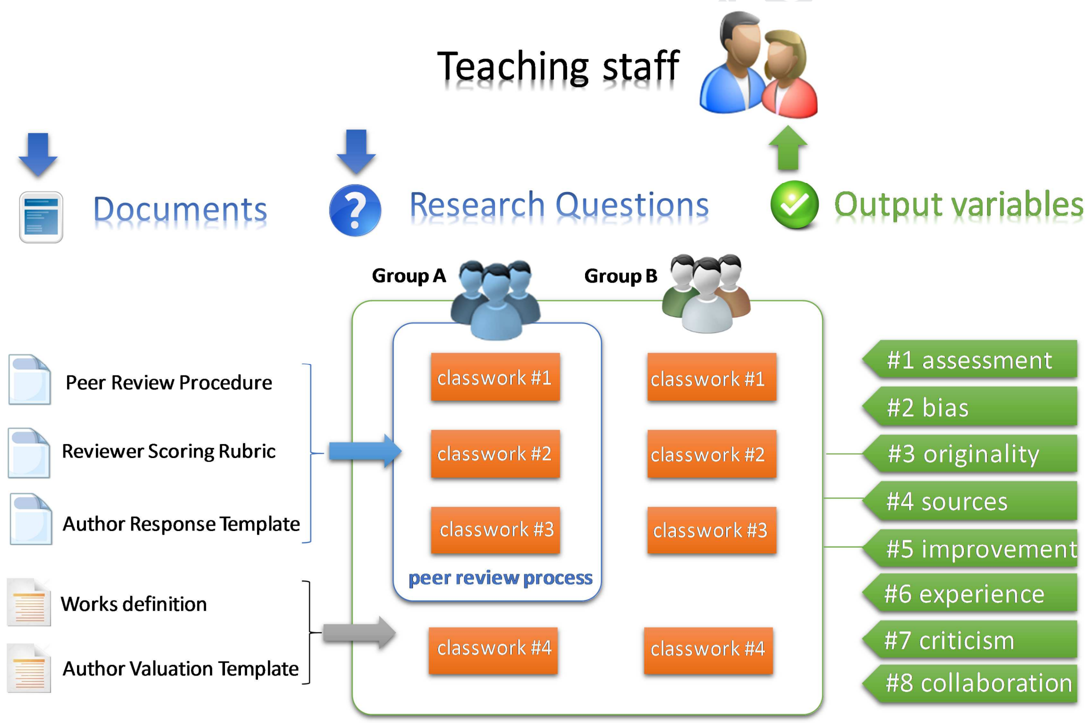

Figure 1: Methodology and elements involved in the case study

4.1. Class assignments

Each assignment was prepared to assess a set of key aspects in order to obtain an estimation of variable behaviours. Other conditions were also observed to help instructors calibrate the peer review process and analyse students' academic performance. This body of class work covered all the variables and aims of this research. Table 4 below describes the main features and the group of variables analysed for each of them.

Table 4

Class assignments involved in the peer review process for engineering students.

Work Description (review rounds)	Aspects to be assessed	Variables analysed
Class work #1 (1 round): A combination of exercises and problems. i.e: numerical conversion to different representation basis exercises and a representation problem.	• Format and layout. • Writing and style. • Correction of results.	#1 assessment #2 bias

Class work #2 (2 rounds): Write a report on a topic of the subject. i.e. write a report about real representation formats and determining their suitability for some identified engineering problems.	• Format and layout. • Writing and style. • Existing copy&paste • Number and quality of sources.	#1 assessment #2 bias #3 originality #4 sources
Class work #3 (2 rounds): Resolve design problems. One problem is particularly difficult. i.e. propose a simple arithmetic unit for basic operators.	• Format and layout. • Writing and style. • Correction and complexity of the design.	#1 assessment #6 experience #7 collaboration #8 criticism
Class work #4 (0 rounds): Write a report and resolve a design problem. i.e. write a report about complex function calculation and propose a design for exponentiation operator.	• Format and layout. • Writing and style. • Existing copy&paste • Correction and complexity of the design.	#3 originality #4 sources #5 improvement

Class work #1 took only one round of peer review. Its main purpose was to make students get to know the peer review process. In this assignment, review comments were not assessed. The teaching staff only checked the validity of comments with respect to the items highlighted in the scoring rubric. Possible bias towards instructors' assessments were also taken into account. In this case, assignments also had to be checked by instructors. The type of answers (numerical scores) of this work facilitated this assessment.

Class work #2 took two rounds of peer review. This work was more elaborate than the previous one. Writing the report required searching for information on internet and to achieve a satisfactory standard of work, many sources had to be consulted. Thus, knowledge discovered by the student depended on the search carried out, and therefore, further exploration of the topic provided better criteria for making suitable proposals.

Class work #3 also took two rounds of peer review. Information search became key to finding the best options. There were many possible arithmetic designs (for example, in the case of the addition operator: carry propagation adder, carry look ahead adder, carry save adder, etc.). Design options known by students allowed them to choose designs most suitable with respect to requirements. In this assignment, review work assessed by instructors was twofold: they assessed both critical comments and improvement comments.

Class work #4 was not peer reviewed. This work was more difficult than the previous three and took more time. Students had to employ all their skills and intelligence in resolving an even more difficult problem. Competences and learning habits acquired in the previous works were essential to complete this task. This work was the 'control work' aimed at validating whether improvement and experience took place as a result of participation in peer-review methodology. The assessment method for this work is the same in both groups and it is made by the teaching staff.

4.2. Results

Specific results regarding aims of this research and academic variables are given below. The results of many of them were closely linked. Although both groups have the same classworks, these comments on the findings have essentially focused on the Group A results because the assessment method of this group is the methodology analyzed in this research. Only variables #3 (originality), #4 (sources) and #5 (improvement) have been analyzed for both groups in order to compare the results. These variables are involved in Classwork #4 which follows the same assessment methodology for both groups (made by instructors).

#1 *assessment*: this variable was covered by class works #1, #2 and #3. Students had to make an effort to do a good job in this area ensuring a fair assessment process. As the course progressed, students made better comments, that is, not just superficial comments, but structural criticism and supported by academic documents, etc. They were encouraged to give a good review to stimulate their critical thinking. Review process by students improves this skill because this activity needs not only to know the right answer, but also to make comments and to propose changes to improve the classwork. This last part of the job requires critical thinking on their mates' works.

The 'Reviewer Scoring Rubric' document and related guidelines given in the classroom by instructors, suggested comparing the results, designs and reports with own responses, looking for alternatives, and finding out better ways from the knowledge available. In general, the marking and the notes provided were reasonable, and properly documented. This is clear evidence that they thought about their review and tried to point out interesting issues.

#2 *bias*: This variable was covered by class works #1 and #2. In short, there was a significantly positive correlation between student and teacher evaluation. It was quite easy to quantify numerical scores, and in this case, they were very close to instructor grades. As far as evaluating reports was concerned, the assessments followed the instructions set out in the "Reviewer Scoring Rubric". In this way, they were also similar to those made by teachers.

#3 *originality*: This variable was examined by class works #2 and #4. Thus, the assessment process of these works includes to check that they have original text and original design approaches. In classwork #2, students of group A were encouraged to look for similarities in bibliographic sources. In this way, the rubric emphasised the importance of producing original works and proposing techniques to detect plagiarism, for example: looking for the text of the works in internet searches and in the referenced sources: comparing the proposed design with ones existing in the literature and web pages or marking very sophisticated text (in this case, the source could had been in English and the student had translated it into Spanish). The peer review could not detect plagiarism among students themselves because they couldn't view all the works. This aspect was especially pointed out by teachers and the importance of producing original works was strongly stated. Students could (and had to) consult the sources but they had to summarise them and draw their own conclusions. Students naturally started with an existing design (explained by the teacher, existing in the lecture notes or in the bibliography), but they had to contribute some new idea to meet required specifications. Results showed that, in general, students produced original works in both groups.

#4 *sources*: This variable was also studied by class works #2 and #4. Four aspects related to sources were highlighted: number, quality, date and language. Students checked these aspects and signalled deficiencies to the author. Results showed that the peer review group (group A) did better work in terms of sources used. Since this was a key aspect to be reviewed, students paid close attention to obtain appropriate citations and references. Increased use of sources in English coming from high quality sources such as journals or conference proceedings was observed in this group. In particular, around 50% of the sources were of this type. In contrast, the works of group B maintain the majority of sources in Spanish or poor-quality sources (around 80%).

#5 *improvement*: This variable was analysed only in work #4. In all cases there were improvements. Work #4 was better than work #1 in both groups. However, the peer review group went further in some aspects. The overall quality of works #4 of students involved in the peer-review was greater. They made better use of sources and explored different design approaches based on modern proposals. There seemed to be an improved understanding of the subject.

#6 *experience*: This variable was analyzed only in work #3. Its result was very much related to the previous one. Students had obviously learnt from the other work they reviewed. In many cases, a significant improvement was observed in the results of group A due to its authors having reviewed other good works. In this sense, students acquired knowledge and skills not only from teachers but also from other students.

#7 *criticism*: This variable was also analysed only in work #3. The issue being addressed by this variable is how well reviewers criticised works, that is, whether rubrics were applied and the diversity and quality of the comments made. To reasonably measure this variable, instructors directly examined comments made by students as reviewers and read the 'Author Valuation Template' to collect students' opinions on the review work. Results were heterogeneous. In general, there were good reviews but there were also poor comments made in a hurry that did little more than checking the rubric.

#8 *collaboration*: This variable was also analysed only in work #3. The role of reviewers was of particular importance in this process, not only to give a critical judgment on the work, but also to improve the final version of the class work through proposals. Following the first three class assignments, the reviewers' work was analysed to define their level of contribution. In this case, the 'Author Valuation Template' was again examined. The focus was on determining whether there were suggestions on better and alternative ways of doing work. In this case, students argued that review comments were useful to improve works, but they mentioned that they should be confirmed by instructors. Thus, they were more satisfied and trusting when the comments came from instructors, despite the fact that comments were very similar.

5. Conclusions and Discussion

Results have been quite satisfactory and many pedagogical advantages have been observed. The learning process was progressive and incremental due to students' constant efforts. In just a few weeks, students understood the new organisation of the teaching-learning process.

Our first finding was that the peer review process enhanced student **motivation** in the subject. This can be perceived by the instructors as a greater involvement of students in the classroom by making an increasing number of questions (on the subject's content and on the methodology itself) and interventions during sessions. The review work by students makes they must study regularly, perhaps daily. Thus, their effort is distributed along the course and they don't forget so easily the acquired knowledge. They are also able to follow the explanations of the lecturer and to assimilate the new concepts that are needed to understand the next lesson. This learning method aids to overcome bad habits such as copy-paste or copy each other, as well as to improve the quality of the bibliographic references.

Participating in this evaluation process was perceived by engineering students as interesting, and it caught their attention, especially when they discovered that this was the system used to make science progress. Collaborating in peer assessment was exciting. All students wanted to join the initiative, and nobody leave the process. Only a very small minority of students were late in making the review job.

The methodology promoted **active learning** where students are involved more actively in their own learning, and therefore, they develop further learning abilities. Therefore, students find themselves in a better position to assimilate new technological evolutions in a global competing world.

In this work, we have reviewed the main peer-review tools for academic contexts and we have proved how the online collaborative platforms enhance the teaching-learning process. Technology is essential to carry out this methodology in higher education. Indeed, this methodology cannot have been carried out without a modern web platform able to handle many students and retrieve assessment data in order to study their evolution and needs. In this way, peer review was also an interesting methodology for instructors. Results show that this technique could **save time** for teachers when handling very large groups. Marks were similar and the main difference lied basically on the time spent in doing the review of each work. Teachers' broad experience enable them to make corrections in much less time than students. From our experience in this work, instructors can save around 50 % to the total assessment time. The first set of classworks could be evaluated by students themselves using this methodology, and only the final work(s) is evaluated by instructors. They also should be involved in resolving the incidents in the process such as delayed reports, disagreements with the reviews, etc.

To properly implement peer-review as a management technique, findings of this research reveal that the design of the scoring rubric document is very important for students to do the job right. This document allows students to know what criteria will apply when reviewing work and what key aspects they should pay attention to. This promotes equality and standardisation in the assessment process. Regarding the specific aims of this work, we discuss below answers obtained on our research questions.

1. *How does the peer assessment activity increase engineers' final quality of work including problems, projects, designs and reports?*

Certainly, our perception was that the peer review process leads to better learning results and increased quality of works. Work standards improve and the teaching staff perceives better habits and attitudes during its execution. This is a very important skill for engineers and therefore, effectiveness of learning is improved in engineering education. We can give two examples: firstly, corrections of classwork#1 were not provided. Instructors observed that when students have to assess other students' works, they must know the answers. There were cases of work with wrong numerical results, but authors made correct assessments when reviewing classmate work. They had obviously learnt the right answer in order to do the review. In our second example, the last class work is the same for both groups. This allowed comparing results of the methodology. Students trained in peer review generally looked for the best option to do the proposed design, and also searched through the literature for existing methods. In class work #4, students knew how to resolve the exponentiation function, usually by the Taylor series decomposition as explained in math courses (and on the Wikipedia website), but this function could be resolved in a more efficient way using the Newton-Raphson algorithm and/or by the CORDIC method. Some students from group A proposed these types of designs after having found them in bibliography on computing arithmetic. These were advanced calculation methods which cannot be found in the standard bibliography on the subject.

The average results of assessment and the collaboration among students are described by Table 5. As can be observed, the quality of final works converged because of this cooperation and these cross reviews. The standard deviation shows this convergence. Thus, the average mark was higher in group A than in group B. The increment of the average mark of the peer-review works was around a 10% principally due to the sharing of knowledge between the reviewers and authors. Thus, the good students acting as both reviewers and authors transfer knowledge and know-how to the other students. Another point of interest is that students assess more positively than teachers. Therefore, their marks are higher.

Table 5. Average student ratings

Average Rating (std. deviation)		
Assessment by Teaching Staff Group B	Assessment by Reviewers Group A	Assessment by Teaching Staff Group A
7.56 (2.32)	8.58 (1.28)	8.28 (1.15)

The improvement in writing is also significant. The final work generally showed better structured documents as a result of the previous training in writing skills. These skills and others such as critical thinking developing are not assessed in these classworks.

However, it is important to note that marks of works based on subjective evaluation such as classroom #4, could be influenced by the average mark of the group. That is, the academic level of the group could introduce a bias in the gradings. Therefore, there is not very much difference between the final marks of group A and B.

2. *How is student behaviour regarding knowledge access improved by means of the peer review methodology?*

The analysis of variables #3 (originality) and #4 (sources) show an improved students' access to knowledge. The review work done by students improved students' access to knowledge. Thanks to this methodology, students have access to their partners' sources, and therefore, they can see a wider range of options. Thus, they can add them to their own works after the first review. The final work provided a clear example of this improvement. Usually, the majority of students use general contents websites (such as Wikipedia), recommended bibliography in the subject and other documentation, mainly in Spanish. The teaching staff warned students about using poor quality sources, but in many cases, students still used them (perhaps due to bad habits and easy access to them). However, students involved in the review process made better use of available bibliography resources and searched more deeply for better sources.

From this finding, we can deduce that students improve their access to knowledge, especially to latest scientific knowledge. This aspect is even more striking when the issue discussed is current and up-to-date. This is taken into account in the design of the assignments. Work #2 dealt with a well-known issue (numerical representation) and a lot of information about it was available in general content web pages, but work #4 dealt with a specific problem where students had to consult specialised sources to find the best options. This is a very important skill for future engineers and scientists.

3. *Does the peer review methodology generate collective intelligence thanks to students' collaboration?*

The analysis of variable #8 (collaboration) provides interesting results about this issue. It has been proven that when a group of students work together on a given assignment, they achieve greater work quality. This collaboration occurs between authors and reviewers for each student work provides an educational experience in which knowledge is successively built. All of them cooperated in the final work. In this sense, we can affirm that collective intelligence arises since the final work was better than individual work. However, it is not clear to what extent overall intelligence increased. This level of cooperation is also produced in the standard group work, but in the review process (one author and three reviewers), the quality of reviews observed in this research depended largely on the motivation and the preparation of each student. Thus, the best students make better reviews and the authors include ideas in their works thus improving the results. However, this level of contribution is not often observed the other way, i.e., poor students providing good ideas to better ones. There is a correlation between best student grades in the four works, but this correlation is weak for the rest of the students.

A positive effect detected in this process is that instructor reviews of comments made by students as reviewers, showed that cases exist of more direct communication than when working in an open team face to face. This fact allows some students to make comments students would otherwise not dare make, being afraid of making mistakes and giving a bad image in front of classmates. Teachers detected that anonymity protected them. This detected benefit can generate positive ideas for improving work and could lead to developing collective intelligence.

The final work after the review process surpassed what students could do individually, but we cannot conclude that real collective intelligence was produced.

Finally, although it is not clear what degree of improvement is directly attributable to peer reviews or attributable to simple iteration and revision, we can conclude that the peer review process enables increasing student performance. Experience shows that typical collaboration between students is poor when writing group reports. Usually, each student writes a part of the report, each part is then pasted together with no one over-viewing the document as a whole. In contrast, added value provided by the peer review process is especially relevant in designing and writing skills, where constructive learning through real collaboration and working in teams takes place.

With respect to limitations, two main drawbacks can be observed: (a) while it is true that the peer review process is able to awaken students' interest in the subject and learning, it can turn into a tedious and boring task when planned to be repeated over a long period of time; (b) this methodology leads to a substantial increase in student workload. They must to do their work and additionally review the work of several classmates. Therefore, it can cause work overload and as consequence, a higher dropout rate in the subject.

In order to better know the weaknesses from the student point of view, a light questionnaire can be drawn to be done at the end of the process.

Teaching staff must be aware of these problems and carefully plan its use in the subject. This methodology can be combined with other traditional instructor-led assessment methods during the course and be applied only to most suitable types of work, such as report writing or complex design problems.

In addition, oral presentations of the class assignments or projects can be also introduced to diversify the assessment procedures and developing other important skills in new information and communication technologies for future science and engineering students.

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-Improved performance of students is produced through collaborative learning.
-Student peer review enhances content assimilation.
-An enhanced learning in several scientific skills is produced.