Assessment of a pedagogical model for stem education: combining technology and collaborative tasks

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Valoración de un modelo pedagógico para la educación STEM: combinar tecnología y tareas colaborativas

Valoració d'un model pedagògic per a l'educació STEM: combinar tecnología i tasques col·laboratives

RECEIVED: 8 JUNE 2022; ACCEPTED: 25 NOVEMBER 2022 ; DOI: https://doi.org/10.55815/413456

ABSTRACT

The polymer industry was boosted in the middle of the twentieth century when industrial production was made feasible. Nowadays, it is really difficult to find many everyday objects that are not made of plastic or contain plastic parts. Thus, polymer science and technology is an essential area in the materials engineering curriculum, where traditional (e.g., extrusion) and novel (e.g., 3D-printing) processing techniques can be discussed. Two pedagogical strategies were used in the present study. In the theoretical classes, a simple model based on an everyday object (i.e., shoelaces) was used as a demonstration of the structure of polymers, while a questionnaire carried out twice was performed in seminars oriented to the resolution of case studies. ICTs were used in both sessions (i.e., Instagram and Office Excel) to assess the learning process. The students determined that this approach resulted interesting for them, which in the end increased their motivation. Both strategies were successful, as denoted by the results of this academic year compared to the previous ones. This indicates that this innovative activity is a model validated by most students, increasing the development of their competencies and their motivation.

Keywords: Active learning; Contextualization; Conceptual Change; ICTs; STEM;

RESUMEN

La industria de los polímeros se impulsó a mediados del siglo XX cuando se viabilizó la producción industrial. Hoy en día, es realmente difícil encontrar muchos objetos cotidianos que no estén hechos de plástico o contengan piezas de plástico. Por lo tanto, la ciencia y tecnología de polímeros es un área esencial en el plan de estudios de ingeniería de materiales, donde se pueden discutir técnicas de procesamiento tradicionales (p. ej., extrusión) y novedosas (p. ej., impresión 3D). En el presente estudio se utilizaron dos estrategias pedagógicas. En las clases teóricas se utilizó un modelo simple basado en un objeto cotidiano (i.e., cordones de zapatos) como demostración de la estructura de los polímeros, mientras que en los seminarios orientados a la resolución de casos prácticos se realizó un cuestionario realizado en dos ocasiones. En ambas sesiones se utilizaron las TIC (es decir, Instagram y Office Excel) para evaluar el proceso de aprendizaje. Los estudiantes determinaron que este enfoque les resultó interesante, lo que al final aumentó su motivación. Ambas estrategias fueron exitosas, como lo denotan los resultados de este año académico en comparación con los anteriores. Esto indica que esta actividad innovadora es un modelo validado por la mayoría de los estudiantes, aumentando el desarrollo de sus competencias y su motivación.

Palabras clave: Aprendizaje activo, contextualización, cambio conceptual, TIC, STEM

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RESUM:

La indústria del polímer es va impulsar a mitjans del segle XX quan es va fer factible la producció industrial. Avui en dia és molt difícil trobar molts objectes quotidians que no siguin de plàstic o que contenen peces de plàstic. Així, la ciència i la tecnologia dels polímers són una àrea essencial en el currículum d'enginyeria de materials, on es poden discutir tècniques de processament tradicionals (per exemple, extrusió) i noves (per exemple, impressió 3D). En el present estudi s'han utilitzat dues estratègies pedagògiques. A les classes teòriques es va utilitzar un model senzill basat en un objecte quotidià (és a dir, cordons de les sabates) com a demostració de l'estructura dels polímers, mentre que es va realitzar un qüestionari realitzat dues vegades en seminaris orientats a la resolució de casos pràctics. Les TIC es van utilitzar en ambdues sessions (és a dir, Instagram i Office Excel) per avaluar el procés d'aprenentatge. Els alumnes van determinar que aquest plantejament els resultava interessant, fet que al final va augmentar la seva motivació. Ambdues estratègies van tenir èxit, tal com demostren els resultats d'aquest curs acadèmic en comparació amb els anteriors. Això indica que aquesta activitat innovadora és un model validat per la majoria dels alumnes, augmentant el desenvolupament de les seves competències i la seva motivació.

Paraules clau: Aprenentatge actiu, contextualització, canvi conceptual, TIC, STEM

INTRODUCTION

One of the main skills for engineers is the ability to solve new challenges [1]. A combination of STEM disciplines (science, technology, engineering, and mathematics) has been shown to have a positive effect on its development [2]. Moreover, active learning has been proven to strengthen engineers' skills (e.g., innovation, leadership, communication, creativity, critical reasoning, enthusiasm…) [3]. However, traditional teaching methods are not efficient enough when these abilities are used with students. These methods have been prevailing in higher education scenarios for many decades, whereas computer-based learning is gradually introduced at universities. This expands the opportunities at the educational level regarding communication, interaction, and collaboration, but the activities proposed must be properly motivated [4]. Thus, the role of universities is fundamental in the education of the human resources that society demands. Attend to the evolution of society and, eventually having a high positive impact on organizations, an approach of technological learning, which is in many cases required [5].

Currently, the presence of information and communication technologies (ICTs) has an effective incidence in the optimization of processes and in its power to connect and reduce distances between netizens when used in high education learning [6,7]. The ICTs have often been used for educational purposes (i.e., audiovisual teaching), while learning theories have recently focused on the student and collaborative learning as an aspect where the use of technical skills is considered useful [8]. Thus, the educational potential of social networks (i.e., Instagram, Facebook, TikTok…) can be based on immediacy and network connections between students. Several approaches have been proposed to apply these technologies for educational purposes, where academic content can be addressed with online collaborations and comments [6]. Social networks are important since they greatly influence the development of the individual, connecting them interpersonally, at a distance, and virtually. Although there is no physical contact between individuals, the essence of social communication remains unchanged [6]. Apart from social networks, there are more ICTs with applications in high-education learning. Traditionally, some of them have been used as visual aids (as is the case of office applications, videos, or pictures), however, their use could be strengthened in the case of higher education levels. Rodriguez-Ayala [9] stated that the use of office applications in the learning process was undervalued, as they could be a tool easily accepted by students, which can improve the teaching-learning process.

Moreover, student motivation is enhanced when they find applications to ideas just learned [10]. Thus, contextualization can be regarded as a strategy to link the learning of skills and academic or further occupational labours. This link is achieved mainly by focusing teaching and learning on specific applications (related to the interest of students) [11]. In this sense, education should always be contextualized with applications based on their daily life and, if possible, with future applications in industry. At this point, personal factors that affect the teaching-learning process should also be noted [12]. The interest of students differs depending on the topic and application, reason why diverse teaching methods are highly recommended to be used in higher education [13]. In this way, a combination of social and applied approaches to technical knowledge found in the technical and engineering sciences can be successful in STEM disciplines.

This work presents an approach of a teaching innovation experience carried out on the subject of Polymeric Materials, for those who studied materials engineering. The course is divided into theory, seminar, and practical content. The innovative experience was applied to the theoretical and seminar activities. In those sessions, teachers used ICT (Instagram) as well as office applications (i.e., Microsoft Excel), connecting the issues addressed in classrooms with real applications. This work applies critical thinking to improve the motivation of students by evaluating the effectiveness of their critical thinking on their course progression using anonymous assessment tests.

CONTEXT OF THE PEDAGOGICAL ACTIVITIES

This innovative activity was applied to students of 3 degrees: a degree in materials engineering (ME), a joint degree in materials engineering and physics

(ME+Phys), and a joint degree in materials engineering and chemistry (ME+Chem) of the University of Seville. The duration of the activity was one semester. The subject is taken in the fourth course of the program, so the students are mature enough to address this new challenge from an advanced perspective. Participation in the activity was voluntary and did not contribute to the final grade of the students. It must be highlighted the heterogeneity of the alumns, as these classes are imparted simultaneously the 3 different degrees (ME, ME+Phys and ME+Chem). Those students that undergo ME+Phys or ME+Chem degrees required a higher cut-off mark (12.137 and 9.900 out of 14 for ME+Phys and ME+Chem, respectively) for admission to the public university than those with a simple degree (5.0 for ME). However, this information about cut-off marks can be an unreliable predictor of the potential success of students at university [14].

Learning in the STEM context develops critical thinking, increases scientific literacy, and produces a new generation of innovators and inventors. Polymer Science and Engineering fit within the multidisciplinary STEM field, being centred on polymers. The word 'polymer' comes from the Greek word *polymers*, composed of *polys 'many'* and *meros 'part'* [15]. Among the materials found in nature and human society, polymers are the main light and flexible materials, with a characteristic low density (around 1 $g \cdot cm^{-3}$) and displaying reversible elasticity [16]. The mechanical behaviour of polymers is related to the rotational degrees of freedom along their macromolecular chains and their corresponding lengths. When they are subjected to an external force, long, flexible macromolecular chains require junction points at the ends of the chains to impart reversible elasticity once the external force drops to zero [17]. The junction points may be due to the existence of covalent bonding among the chains (cross-linking). The presence of certain side groups (*e.g.,* aromatic) or massive cross-linking makes polymers less deformable and with greater rigidity. The glass transition temperature, T_g, is an important parameter to consider in reducing flexibility: below T_g, rigid glassy materials are found, while at temperatures above T_g, polymers display rubbery behaviour, due to the hindrance of secondary interactions (*e.g.,* hydrogen bonds) during glass transition [18]. The understanding of these concepts is essential for students in a Materials Engineering degree, as they are also of great importance during polymer processing.

DESCRIPTION OF THE ACTIVITIES

The innovative approach was first designed and applied to the theoretical lessons of Polymeric Materials. Seminars were held later, so students were already used to an innovative approach to the subject. The activities followed in both modules were different since the context was different (*i.e.,* smaller groups in seminars) and the willingness of students to innovative activities was higher once they enjoyed the theoretical lessons. Chalkiadaki [19] stated that teachers aim to have a greater predisposition of students to innovative activities. Thus, different activities properly coupled in rational order can increase the student's predisposition to change traditional learning systems.

Theoretical lessons

In previous courses, there was a significant number of students who failed to clearly define basic concepts of the polymer field. This lack of knowledge was found even if students stated in the questionnaires that they had dedicated time to its preparation, the influx to the classrooms was good, and they attended the seminars. For this reason, in parallel to the innovative activities, some extra time was given to the first topics of the subject to clarify these basic concepts that set the ground for the rest of the course. In addition, an innovative cycle was applied to work with these concepts. Figure 1 illustrates the flow diagram followed during the theoretical lessons. The definitions related to polymer science that was chosen for the first part of the subject were: thermoplastic, thermosetting, crosslinking, and secondary interactions.

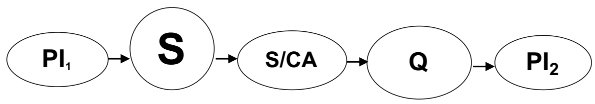

Figure 1. *Strategy for the innovative activity. PI1: Previous ideas of alumni on the concepts; S: speech on the concepts by the teacher; CA: Contrast activity; Q: Questions to alumni to check acquisition of concepts; PI2: ideas of alumni after the innovative activity.*

Briefly, these are the approaches followed in each activity followed for the first part of the subject.

- **IA$_1$**: In the classroom, students are asked about what they think it means that a polymer is thermoplastic or thermosetting. If participation is low, the teacher guides them by telling them to think about the etymology of the word and the behaviour of common plastics with temperature. Then, some students are naturally encouraged to answer correctly: Thermoplastics deform with temperature, while thermosets do not. However, when asked if they can imagine the reasons why no satisfactory answer was found.

- **S:** The concepts specified are clearly explained with the help of slides and the blackboard. The teacher focuses on the importance of secondary interactions in the case of thermoplastics and on how covalent bonds crosslink in the case of thermoset polymers.

- **S/CA:** Days later, they are asked again if they could define the same concepts. The answer is given orally. To check their knowledge, a simplified model is then employed for describing the concept. Polymer demonstrations are really important within STEM education curricula, as they not only afford the opportunity to introduce students to polymers but also provide a tool to educate students about the impact polymers have on the planet [20]. A shoelace model was proposed in this course: two pairs of shoelaces that simulate the behaviour of 4 polymer chains are used. The tangle of intertwined cords simulates an amorphous polymer with thermoplastic behaviour because it is possible to untangle them without much problem (secondary interactions). When a series of knots are made between the strands (covalent bonds), they cannot unravel, simulating thermostable behaviour. Since the visibility of the laces may not be optimal from where the students sit, a projector is used to show photos of the laces in the different cases, as well as a video. The potential recyclability of different polymers was discussed in the classroom, as thermosets are hardly recyclable, but thermoplastics could be melted and reshaped to a certain extent.

These photos and videos (https://www.instagram.com/reel/CUrh4BiocAP) were posted at the end of the class on an Instagram account of the subject (https://instagram.com/matpolplus?igshid=YmMyMTA2M2Y=). In this way, even the students who did not attend the lessons can access the presented model.

•**Q**: an anonymous form was made for their assessment from 1 (completely useless) to 5 (very useful) in order to know the opinion of the students about the model and its usefulness. In addition, they were voluntarily asked questions about the theoretical concepts, considering that previously some students had answered correctly when asking about these concepts. Those questions were:

•Q1. How do you assess the usefulness of the proposed shoelaces model for the different concepts about polymers (thermoplastic, crosslinking, crystallinity...)?
•Q2. How does this simplified model fail to properly describe polymers?
•Q3. If you have noticed some flaws in the model, can you think of how the model could be modified to get closer to reality?
•Q4. Can you think of a similar model with everyday objects? (eg, spaghetti)

•**PI$_2$:** The answers of the students are analyzed not only to evaluate the usefulness of the model for later courses, but also to evaluate the quality of the ideas acquired by the students when they find the insufficiencies of the model, and their proposal of new models that emulate the explained concepts.

Table 1 summarizes the activities carried out, indicating the time dedicated to each section.

Table 1. *The activity sequence followed in the theoretical lessons.*

Activity	Name	Time scheduled	Resources
PI$_1$	**Previous Concepts thermoplastic/ thermoset**	5 min	Dialogue with students
S	**Scientific explanation**	20 min	Slides. Blackboard.
S/CA	**Simplified model**	20 min	Shoelaces model. Pictures & Video. Instagram. Dialogue with students
Q	**Online Form**	15 min	Google forms
PI$_2$	**Analysis of results**	10 min	Dialogue with students

Seminars

Seminars are aimed at connecting theoretical concepts with problem-solving ability. Before the seminars, the students must briefly view and analyse the material that gives them clearer previous ideas. This approach reduces the theoretical explanation, allowing us to focus more on the practical part of the seminars. In the final part, students will work on solving problems in groups and using a spreadsheet program. It is interesting to use spreadsheets, since after the resolution of a generic problem the parameters of the models can be modified, which allows students to realize the consequences of the

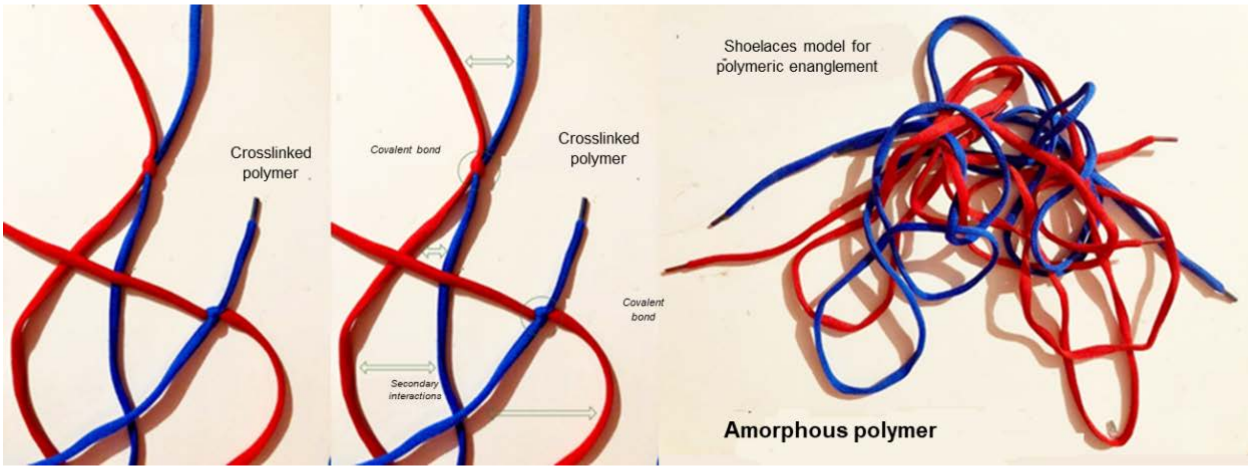

Figure 2. *Shoelace model for thermoset polymers (A) and shoelace model for thermoplastic amorphous polymers (B)*

change and how the behaviour of the material is affected. The seminar aims to work on the exercises in groups, aiming to force students to interact with themselves. This would help to expand the zone of personal development of the students. Figure 3 illustrates the organization of the practical part of the seminars:

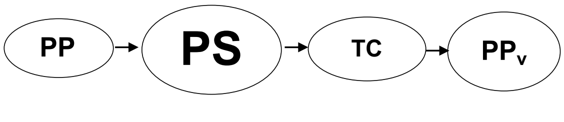

Figure 3. *Strategy for improving student participation in seminars. PP: Problem proposal and explanation; PS: Problem-solving (by students); TC: Theoretical clarification; Q: Questions to alumni to check acquisition of concepts; PP_v: Problem proposal/visualization.*

Briefly, these are the approaches followed in each activity during the seminars on Polymeric Materials:

- **PP:** The students are joined into small groups of two or three students. The problems are proposed and explained on the blackboard. These problems are connected with the content of theoretical lessons, tackling basic concepts and connecting them with specific and advanced concepts.
- **PS:** Now, the students solve the problems themselves. If they have any doubts, they must discuss them with them, before asking the teacher. They are given a relevant time to try to solve the exercise. They must solve it manually and translate it into a spreadsheet.
- **TC:** The resolution of the exercise is carried out on the blackboard. The exercise is solved by the contribution of the different groups, which need to reach an agreement if the answer differs. Following this strategy, they can compare the results and identify possible errors.
- **PP_v:** A new problem is proposed for the next session, and the students are encouraged to solve it at home. In the next session, they will have 25% less time to solve it. The problem is connected to the previous one and also uses concepts later developed.

Table 2 summarises the activities carried out, indicating the time dedicated to each section.

Table 2. *Activity sequence followed in the theoretical lessons.*

Activity	Name	Time scheduled	Resources
PP	**Problem proposal and explanation**	10 min	Blackboard, oral communication
PS	**Problem-solving (by students)**	35 min	Spreadsheet, calculator, Dialogue with students
TC	**Theoretical clarification**	10 min	Blackboard, Dialogue with students, scientific argue
PP_v	**Problem proposal/visualization**	5 min	Blackboard, oral communication

RESULTS AND DISCUSSION

The evaluation of the different activities described was not trivial. The new methodology applied to this course was evaluated using questionnaires that aimed to detect changes in the mental models of the students.

In theoretical lessons, the questionnaires were used by the teacher to check if the students understood correctly the concepts described in the classes, promoting critical thinking when filling the questionnaire proposed. The analysis of the answers given permitted to adapt the syllabus of the subject to the progression of the students.

On the other hand, the questionnaire given at the seminars was delivered to the students twice, before and after carrying out the innovative teaching activity. Among the different possibilities of questionnaires (e.g., multiple-choice answer, short answer, true/false type, open answer…), this study used open questions [21]. Open questions can reduce or even eliminate the random answers to the evaluation of the activity (for instance, compared to multiple-choice type). Thus, it dilutes the possibility of a correct response from a student who does not know the topic or scope of the question. Additionally, open questions allow students to show the grade of knowledge about the matter that has been questioned, using their own terms [22]. Moreover, the students were also asked about the evolution of the activity. In seminars, oriented to the resolution of case studies including calculations, the questionnaire set the student in a certain context and then six questions related to that setting were made, related to both theory and seminars. Introducing concepts related to a topic in a certain context has clearly shown that it helps students to correlate and interconnect the different concepts developed during the lessons [25]. The open questions propose to connect not only the concepts of the seminars but also with those concepts previously learned in theoretical lessons in their daily life and also with some from other subjects.

Furthermore, in both cases, students were encouraged to use a pseudonym instead of their name, since the aim of the questionnaires was to evaluate the activity and not the students' skills. In this sense, they feel free to express their answer without the pressure of being evaluated [23]. However, it can be noticed that when these questionnaires were used as a tool to evaluate students, the students must show real names or an identification number or code that directly referred to them [24]. The students could answer the questionnaires either on paper or through a link or QR code to access virtually to it in the first 5-10 minutes of the lessons. In this way, the participation of the student could be enhanced.

THEORETICAL LESSONS

Lessons were addressed as in previous courses. However, the innovative activity above described (section 2.1.) was developed. It is important that students do not realize the alteration in their learning procedure, especially in a context where most of the lessons are followed in accordance with traditional learning methods [26]. When analysing the answers given by the students to the five questions (Q1-Q5, section 2.1.) at the end of the innovative activity, it was found that:

•Q1. Figure 4 shows the evaluation given to the innovative activity by the students. This is also known as the perception that students have for a specific discipline, which is essential for their motivation [27]. Most students found the proposed model quite useful to help them understand concepts about polymeric materials. No student qualified for the model with a low score (i.e., 1 or 2).

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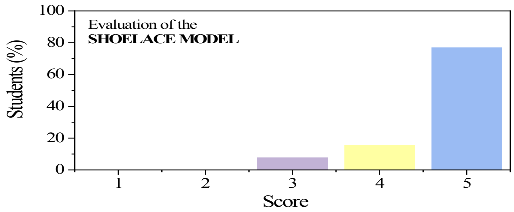

Figure 4. *Evaluation of the innovative activity based on the shoelace model by students.*

•Q2. When the students were asked about the errors or facts that the shoelace model did not consider when compared to reality, most students (90%) pointed out some flaws of the model correctly, such as:

A. There was no distribution of molecular weights, as all laces were of the same length.

B. There was no ramification, as the shoelaces were straight and no branches were attached along the main chain.

C. The effect of temperature cannot be described through this model (e.g., thermosets formation)

When answering this question, students are asked to question the model analyzing the real facts they are learning in the classes. Thus, critical thinking is promoted through the completion of the questionnaire, which is beneficial for the learning process as most critical thinking theorists argue that learning should always incorporate critical thinking [29].

•Q3. Once the students detected the flaws of the model, they were asked to propose a modification of the model to make it closer to reality. More than a half (60%) proposed modifications to the simplified shoelace model, like:

A. Students proposed to cut the laces so that there could be different lengths, and a more realistic distribution of molecular weights could be achieved (Solution to flaw A).

B. They also proposed to make a knot of short laces to the main longer lace, so that ramifications could be described, and flaw B considered.

C. No solution was found to describe the effect of temperature on the polymeric chain of a thermoset material. It could be concluded that this model is not so valid for describing crosslinking.

•Q4. The students were asked to propose an alternative model that could be as valuable as the shoelace model studied. Then, around half of the students proposed different models to simulate the behavior of a polymer that is flowing or not depending on the crosslinking degree: a mess of cables, entangled hair…

Finally, photos and videos of the model were uploaded to the social media account of the classes, obtaining many "likes" from the students.

The model proposed, in spite of its simplicity, promoted conceptual change among students who already had ideas about the polymer structure. The term conceptual change has been used to name the development of new concepts by restructuring existing concepts, being a particularly profound kind of learning [28]. The application of this innovative activity has been successful, having fostered the interest of the students, also known as student motivation.

Among the difficulties found during this activity, it could be highlighted at some point the lack of student participation. When asked, only 2-3 students typically raised their hands to answer the questions asked. In this sense, the development of the activity could be improved in future years if the questions are proposed as a quiz, where at the end of the course there is a classification of students answering. In any case, the participation of the rest of the students was encouraged by emphasizing the importance of participating, despite possible mistakes. Moreover, this model also allowed the lecturer to clarify certain concepts that some students found hard to understand, as expressed in previous classes.

Seminars

The open questions proposed in the seminars on Polymeric Materials course were as follows:

The student was told to figure that he or she was in a car repair shop, where materials with different behaviour were found. Then, the following precise questions were proposed:

- **Question 1**. The first thing you find is a spring; you take it and press from one of its edges, with a constant force while the other edge is laying perpendicular to the ground. You managed to deform it. What kind of response would you say its deformation has? Is it time-dependent?
- **Question 2.** Then you take a hydraulic piston, and you press one of its ends with a constant force, deforming the piston. What kind of response would you say its deformation has? Does it depend on the time during which the effort is applied?
- **Question 3.** After that, you pick up a tire that is lying on the floor around the garage and press again, as you did with the two previous elements, deforming it. Is its answer the same or different from the previous items? What kind of response would you say his deformation has? Does it depend on time?
- **Question 4.** They just changed a tire, the car was placed outside in the sun and the tire is still

hot (40 °C), what do you think will happen with its relaxation times if we compare it with an identical tire that was inside the workshop at 30 ° C?

- **Question 5.** In the garage, there is a fire due to an explosion. What would happen to the plastic that the bumper of one of the cars inside the garage is made of?
- **Question 6.** What is likely to happen to the tire if it is hit hard while its temperature is -150°C? Why do you think that would happen to him?

This questionnaire was answered by two groups of 15 different students.

Figure 5 shows the four levels used in the present study to classify the students' responses to each question: level 1 represents the less developed mental model as the student cannot give a proper answer to the question, not only because the answer is wrong, but because the ideas seem not to be clear. It might also be caused by their previous ideas (if it is the first test) that do not allow them to develop congruent thinking related to the topic; level 2 indicates a slight knowledge of the topic, which allows the students to explain their ideas without using proper concepts or language related to the topic; level 3 corresponds to students who showed good reasoning and used adequate language; When the answer was classified at level 4, the students could interconnect the concepts related to the topic between them or with others learned in the same subject or another.

The fact that an inverse pyramid is selected as an illustration aims to represent the larger number of abilities or their capacity to manage the concepts to achieve higher mental models as they reach a higher level.

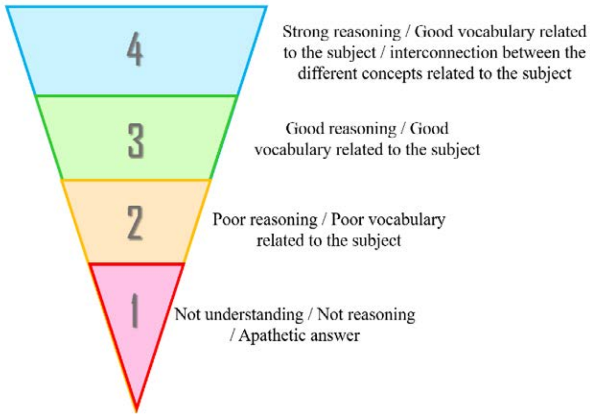

Figure 5. *Four student mental models presented as an inverse pyramid.*

The students answered these questions before and after receiving the explanation. Before the seminar, the responses give the educator an idea of the previous knowledge of the students, and provide insight into the curriculum planning, and planning instructions for the students to take the main profit of the lessons [30]. Other studies have highlighted that evaluating the mental models of students allows educators to identify potential impediments to learning [31] as mental models define an analytical interpretation of reality [32]. On the other hand, the tests assessed after the seminar give an idea of the skills developed by the students during the present course, and they are key in many cases for the overall assessment of the subject [33]. In addition, the comparison between both stages of the learning process helps to elucidate the progression of the different students.

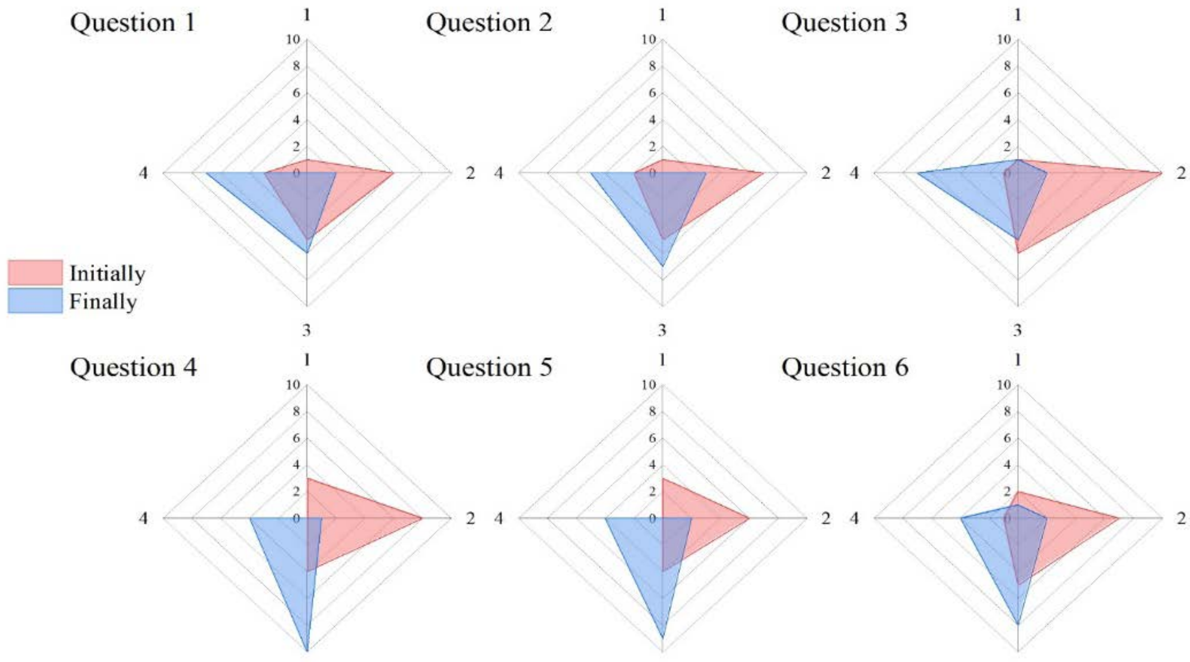

Figure 6. *Assessment of student responses on a 4-level scale (1: apparent lack of knowledge; 4: ability to interrelate newly acquired concepts to previous ones) for the 6 questions included in the questionnaire used at the beginning and at the end of the seminars.*

Therefore, the main goal of an educator is to encourage students to develop higher skills, as this would be a clear sign of a satisfactory teaching-learning process. Thus, the expected result is that the students show higher levels at the end of the lessons than the ones shown before.

Figure 6 shows the score obtained by the Polymeric Materials students for questions 1-6 before and after attending the seminar. For each question, the number of students ranked at each level is also plotted.

Clear differences between the tests carried out before and after the lessons can be observed. In the former (pink colour in Figure 6), the vast majority of students showed answers that correspond to a level 2 mental model. However, the number of students who presented level 4 was negligible, being only one or two of the students who reached that level on certain questions. This shows that initially, students lacked previous ideas that allowed them to elaborate complicated ideas about the topic that is going to be explained [33]. A great improvement can be observed when results obtained the second time they completed the questionnaire are compared with those obtained initially. Thus, the second time around, the students answered in a way that fit better into more complex mental models, since they were mostly in the 3 or 4 levels. This evolution could be clearly stated in Figure 7, in which the average main values of all answers to each question are illustrated. So, in general, there is a transition in the way students develop their ideas, moving from the simplest mental models to the most complex [34]. Van Merriënboer and Sweller [34] also indicated that the current view of cognitive load theory to achieve complex learning suggests that the connection with real-life tasks boosts the learning process. Thus, the results indicate that the teaching-learning methodology followed by the students was able to better interconnect the initial concepts and ideas of the students with those learned during the sessions.

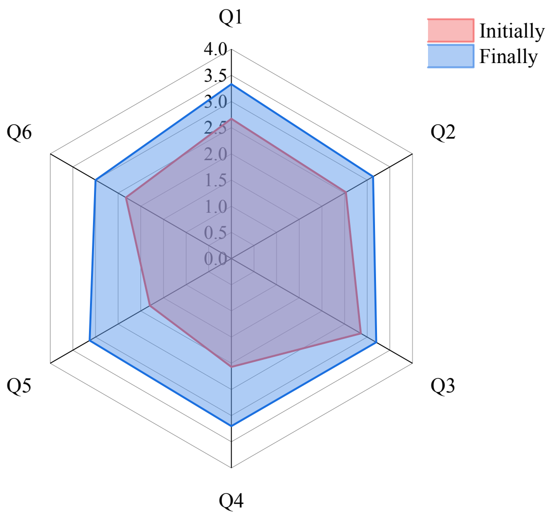

Figure 7. *Average values for the students' mental models developed in each of the 6 different questions presented in the questionnaires, before and after the seminars.*

The questionnaires evaluated in this way give the general evolution of the students. However, it does not allow us to evaluate the progression of the students. Thus, the evolution of students has also been conducted. Table 4 shows the criterion followed to classify the evolution of the students. This work used a five-level classification, attending to the steps (levels) they moved in the assessment tests performed before and after the innovative activity.

Table 4. *Evolution of the students through the classifying system used.*

Symbol	*Classification*
↓	Students whose mental model gives one step back
≈	Students who do not change their mental model
↑	Students whose mental model gives one step up
↑↑	Students whose mental model gives two steps up
↑↑↑	Students whose mental model gives three steps up

Figure 8 shows the sum of the status of the individual students after evaluating the questionnaires before and after attending the seminar. Obviously, the most desired result is that the majority of students move one or two steps up after a teaching-learning process, avoiding those that maintain the level or go back. Moreover, the maximum achievement would be the shift from 1 to 4 (three steps), however, this case was not observed in this learning process.

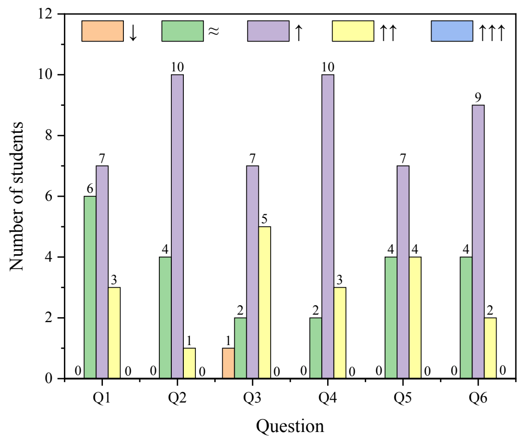

Figure 8. *Average values for the mental models developed by the students in each of the six different questions presented in the questionnaires, before and after the lessons.*

This graph shows that only one student showed a step back (↓) in their evolution of the mental model (exclusively for Question 3). This is probably related to a very poor response in both questionnaires, where the frontier between two steps is not always well defined [35]. However, for the rest of the questions, no student showed a similar evolution, being always null for the students who went a step back. This might be related to the fact that the questions proposed help together with the seminars to improve the knowledge of the students on the topic, probably related to the correlation between the question proposed and the reality of the students [36]. Unfortunately, the step "≈" was followed by 4 students in most cases (reaching up to 6 in question 1), suggesting that these concepts must be addressed in the following seminars for a longer time. In addition, these questions were also discussed in class to reinforce these concepts.

As a counterpoint, Figure 8 also indicates that a large number of students moved one step forward (↑) which showed an improvement in the way they analogically analyse the question and a better formulation of the answer [37]. This was the most repeated shift for all questions, with at least 7 students who took a step forward on the same question. Furthermore, there are also students who manage to go two steps forward, being up to 4 or 5 in question 3 or 5, respectively, which represent a third of the students. Considering that this study was conducted in a small group (15 students), this figure indicates that around 11 over 15 (73.3%) students showed a positive evolution (at least one-step shift), which is a sign that the teaching-learning process was satisfactory, and the activity helped students to improve their skills.

Overall assessment

Another point to evaluate the development of the activity is to compare the competencies developed by the students when the innovative activity was developed or not. For this comparison, we can analyse the marks of the students (since they come from the evaluation of competencies). In this sense, all students (100%) from all degrees (ME, ME+Phys, ME+Chem) that attended the evaluation test passed the course (score of 5 or higher). Note that the qualification considers not only theoretical lessons but also seminars (experience described in the next session). Figure 9 shows the percentage of presented students who passed as a function of BSc and academic year (i.e., shows the students that achieved the competencies required). If the comparing the statistics with those obtained in the previous courses, the main differences are found for the ME degree. Typically, the percentage of students passing the course was lower in that degree, and in the course of the present study, students who followed the classes were quite successful, independently of the degree. Thus, it was clear that the strategies followed were quite successful when the development of competencies was analysed.

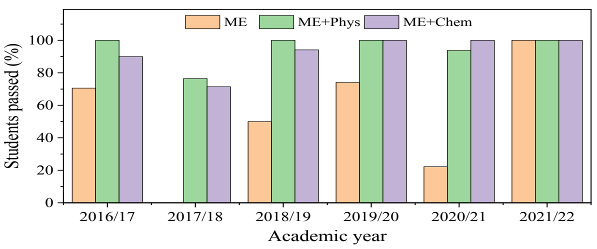

Figure 9. *Percentage of presented students passed as a function of BSc and academic year*

CONCLUSIONS

The present study was focused on the teaching of Polymeric materials, within the Materials Engineering framework. It should be pointed out the heterogeneity of the different students, which requires a methodology useful for all of them. Two different strategies were used for the theoretical classes and the seminars oriented to the resolution of case studies. In theoretical lessons, it was found how a basic model based on everyday objects was an effective pedagogical tool to describe different aspects of the polymers structure and its effect on their physicochemical properties. The model itself and its posterior analysis through the answering of a proposed questionnaire were a good exercise so that students go deeper on the subject, helping to promote critical thinking. Moreover, most students found interesting the activity (92.3 scored 3-4 out of 5), can be related to the motivation of these students. Moreover, the use of open questions before and after seminars was imparted helped to assess the learning process. These questions were the starting point to build the knowledge, and at the same time as it helped to correlate the theoretical and seminar lessons. ICTs were used in both, theoretical lessons and seminars, in the form of social media or spreadsheets. They helped to support the resolution of the case studies through the seminars or to correlate the theoretical lessons to the student's reality, which was found quite successful in developing the competencies aimed. Eventually, when the evaluation at the end of the course was compared to those of previous courses (where there was not a proper schedule of innovative activities), greater scores were found, which could be related to the efficiency of the pedagogical approach proposed. Therefore, future works will implement this approach in other classes and subjects, using both models based on ordinary objects and spreadsheets to solve different versions of the same problem.

ACKNOWLEDGMENTS

This study is part of the ECO-CHEM-NET Project 23966. The authors would like to acknowledge the University of Seville (thorough III Plan Propio de Docencia) for the financial support supplied.

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