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Embracing the efficient learning of complex distillation by enhancing flipped classroom with tech-assisted gamification

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ABSTRACT

Our students are digital natives and smartphones are part of their identity. However, the use of mobile devices in the classroom continues to be a non-integrated issue. For academic purposes, teaching actions involving smartphone apps expressly linked to student participation could be an opportunity to improve their performance. Under this premise, the use of the Quizizz app as a way of enhancing the flipped classroom methodology is herein proposed. The reported experience took place within a mass transfer separation course, at the Master level, during the academic courses 2021–22 and 2022–23. Enhanced distillation, a topic that is instrumental to future professionals in the field of Chemical Engineering, was addressed. It was found that the proposed approach allowed the students to better interpret the vapor-liquid and vapor-liquid-liquid phase equilibrium diagrams. Hence, the students demonstrated more skilled performance when they were asked to propose suited separation schemes (complex fractional distillation) using the Aspen Plus process simulator. Such success was not only in terms of deeper understanding but also on the observed predisposition towards autonomous learning.

1. Introduction

Fractional distillation, common to a list of industrial chemical processes, is the main mass transfer operation and, therefore, instrumental to chemical engineers. Distillation involves the mass transfer between vapor and liquid, in such a way that the vapor is enriched in the lightest compound(s) as it rises in the column. In turn, the liquid is enriched in the heaviest compound(s) as it goes down to the bottoms. If the case of binary mixtures, if these present a minimum/maximum boiling azeotrope, the separation results to be more complicated. In homogeneous azeotropes, the separation may be feasible if a change in pressure yields a shift in the azeotropic composition (the strategy is called Pressure Swing Distillation, PSD). In Binary Heterogeneous Distillation (BHD), the condensed distillate splits into two immiscible liquids, light and heavy phases, which are sent to the respective columns. The methods described are referred to as enhanced or advanced distillation (Schweitzer, 1997; Wankat, 2017).

Calvo and Prieto (2016) remarked the importance of learning advanced distillation processes in Chemical Engineering (ChE) studies. Their approach was implemented within "Advanced separation processes", a fourth year course of the ChE degree. It involved the use of Aspen Plus and a project-based learning methodology. In a similar way, Roman and García-Morales (2019) reported the use of Aspen Plus case scenarios intended to help students explore azeotropic distillation by their own. Process simulators enable the students to propose separation strategies. In fact, according to Ravi (2023), both project-based and computational assessments in ChE studies have received the highest level of recognition in terms of the three dimensions (realism, cognitive challenge and evaluative judgement) of the so-called authentic assessment model. Authentic assessments assess students' ability to leverage technical expertise to solve problems mimicking real-world scenarios and challenges (Villarroel et al., 2018).

Even so, phase equilibrium diagrams are the pillar of equilibrium-staged separations. In consequence, the students first need to be able to interpret the diagrams correctly for the sake of getting the most out of the simulator. On these grounds, modern studies credited games with some advantages in education from different angles (behavioral, motivational or cognitive). The application of games that have an explicit and carefully thought-out educational purpose in different ChE subjects at the Bachelor's and Master's level has been discussed by Díaz et al. (2024).

Multiple choice question assessments have been reported to be a

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helpful tool to identify and correct student misconceptions and their use in this regard has a grounding in the wider pedagogical literature (Ravi, 2023). Within Electronic Learning, mobile learning is a particularly interesting resource, since it allows access to content at anytime and anywhere, and is carried out through mobile devices (smartphones or tablets) connected to a wireless network. It allows immediate interaction between teacher and students, can be adapted to the needs of students and provides instant feedback (Roman et al., 2021a). In that respect, online student response systems (SRS) have been proven to yield meaningful learning of the fundamentals, making the everyday classrooms more engaging and fun, increasing motivation, and, in general, helping create a more pleasant learning environment. Based on gamification and immediate feedback through the use of the Wooclap software, Moreno-Medina et al. (2023) reported improved achievement and motivation of the students within "Mechanical Design of Equipment", a third year ChE course. Such a feature, timely feedback, was also highlighted by Roman et al. (2021a) who implemented a student-centered learning strategy assisted by the Socrative app. The strategy was intended to enrich the teaching–learning process and promoting interactive learning in a "Polymer Technology" course taught in Chemistry and Chemical Engineering Bachelor's degree programs. Caserta et al. (2021) used smartphones as support tool in large classroom settings of a "Thermodynamics" course, at the undergraduate level, in the ChE curriculum. Thermodynamics was chosen as representative of engineering courses requiring high-level cognitive skills for problem solving. The SRS monitoring capability allowed paving the way to personalized tutoring and improved student engagement. Martín-Sómer et al., (2024) presented an experience using various interactive tools (ClassFlow, Moodle, Wooclap and Kahoot!) with the aim of increasing student involvement in both online and traditional face-to-face instruction within a "Fluid Mechanics" course also belonging to ChE.

There is a list of free and easy-to-use platforms that allow students to answer, from their own smartphones, questions posed by the teacher. Table 1 presents the most popular ones, with some characteristics of interest. Please, note that the detailed features are at the time the experience was first carried out, 2021–22, and may have changed since then.

With all the above ideas in mind, the present article reports our own experience on the use of the Quizizz app (https://quizizz.com/) to assist learning on complex distillation through a flipped classroom approach, enhanced by the integration of gamification. Hence, the present work is based on two **hypotheses**: a) that flipped classroom assisted by mobile learning gamification would help the students perceive better the fundamentals of complex (azeotropic) phase equilibrium diagrams; b) that a better understanding on the phase equilibrium diagrams would improve the students' performance on the Aspen Plus simulation sessions.

2. Research framework and objectives

According to all the above, it is of relevant interest to propose a learning experience whose strategic **research framework** is based on the following questions

- Is it possible that the use of the mobile phone becomes an ally of the teacher in the classroom instead of an enemy, facilitating the study of specific contents?
- Can we take advantage of smartphone-involved classroom competitions if they require previous autonomous work?
- What aspects of the teaching methodology involving flipped classroom with gamification through interactive response systems have the greatest impact on student learning?

The **specific objective** of the strategy was to improve understanding

Table 1
Interactive response systems most widespread among the Higher Education teaching community, and their "free version" features.

	Kahoot! https://kahoot.com	**Socrative** https://socrative.com	**Quizizz** https://quizizz.com	**EdPuzzle** https://edpuzzle.com	**Plickers** https://get.plickers.com
Maximum no. participants	50	50	500	No limit	63
Was it possible to search other people materials?	Yes	No	Yes	Yes	No
Interface	Very appealing	More formal	Very appealing	Appealing	Appealing
Popularity	Very high	High	Medium	Medium	Medium
Was it posible to assign time to each question?	Yes	No	Yes	No	No
It enabled to add…	◆ Images ◆ Videos	◆ Images Videos	◆ Images Videos	Images ◆ Videos	◆ Images Videos
Was it possible to assign tests as homework?	Yes	No	Yes	Yes	Yes
Was it possible to import questions from Excel?	Yes	Yes	Yes	No	No
Was it possible to export results to Excel?	Yes	Yes	Yes	Yes	No
Test types	◆ Multiple choice ◆ True/False Short answer Long answer Survey	◆ Multiple choice ◆ True/False ◆ Short answer Long answer Survey	◆ Multiple choice ◆ True/False ◆ Short answer ◆ Long answer ◆ Survey	◆ Multiple choice ◆ True/False Short answer Long answer Survey	◆ Multiple choice ◆ True/False Short answer Long answer Survey
Other features: it allowed…	• Creating groups of teachers to share material • Importing questions from your own or another teacher's bank	• Sharing tests with other teachers through a URL	• Creating a lesson that combines slides with questions	• Uploading your own video in avi, mov and mp4 format (max. 1 GB) • Searching and reusing videos from the platform	• Pasting block of questions from MS Word, pdf or web page • In gamification mode, the answer is given through bidi code cards (not via mobile phone) • The teacher needs to install it in own device (online use is not an option)

of the complex phase equilibrium diagrams as the starting point to design separation sequences of binary azeotropic mixtures. Furthermore, other sub-objectives derived from this project were:

- Designing a methodology which allows students to learn by understanding rather than memorizing.
- Embracing the concept of "digital culture" as a way of developing student-centered methodologies, as promoted by current Higher Education policies.

3. Description of the experience

3.1. The chosen contents

The experience has been carried out over the last two academic courses, 2021–22 and 2022–23. The course is called "Advanced analysis and design of mass transfer separation operations". It corresponds to the first year of the Master's Degree in Chemical Engineering, at the School of Engineering, University of Huelva, Spain. The course is compulsory and imparted over 60 hours. The contents and distribution of on-site teaching hours are briefly exposed in Table 2.

The theoretical contents are put into practice in problem solving workshops, always using MS Excel spreadsheets (every day, the students need to bring their own laptops to the classroom). Apart from that, specific contents corresponding to blocks i) and ii) are addressed in the computer lab using the Aspen Plus process simulator. The case studies dealt with are detailed in Table 2.

With regard to the matter of interest in the present work, i.e. enhanced distillation, all the practical work related to block ii) is traditionally dealt with using the Aspen Plus simulator. This is because distillation schemes involving complex mixtures are too difficult to be designed by the methods commonly used for non-azeotropic mixtures (McCabe-Thiele and Ponchon-Savarit). This issue was addressed in a paper previously published by the authors (Roman and García-Morales, 2019). The students are guided by the lecturers all the way through the process of analysis of the equilibrium data, laying down the flow diagram for the separation and planning the strategy for achieving a fully converged simulation. When all the Aspen Plus sessions are completed, the students, in pairs, are assigned an exercise consisting in a simulation involving the separation of an azeotropic mixture. By the way of example, two typical exercises are provided as supplementary material (download). As can be seen, much information is missing in the problem statement such that the student is welcome to make sensible proposals. This type of open-ended exercise is particularly well suited for courses whose main thrust is to help students develop life-long learning skills, think creatively and innovatively, and exercise engineering judgment (Abulencia and Theodore, 2015; Savage, 1990).

The students are given two weeks to complete the simulation and to report the results. They have free remote/on-site access to the computer room. They are asked to explore the separation of a binary azeotropic mixture by means of complex distillation schemes (either PSD or BHD), using the Aspen Plus process simulator. Aspen Plus provides nice and accurate phase equilibrium diagrams as long as the property package (equation of state, activity coefficient method, etc.) is wisely chosen (Carlson, 1996). Analyzing the phase diagrams enables the students to identify separation strategies. Thereby, the students are empowered to design feasible distillation setups. For the case of a methanol/n-hexane mixture, with a heterogeneous azeotrope at ca. 51 ºC at 1 atm, the method is exemplified in Fig. 1**a**. It shows the analysis of the corresponding VLL phase equilibrium diagram (left) and sketch showing the proposed complex separation (right). The equilibrium data were generated via Aspen Plus using the UNIQUAC/Redlich-Kwong method (Sandler, 2015). According to the diagram, the bottoms will correspond to pure components, whilst the distillates will have the heteroazeotropic composition, i.e. x_{Ht}=0.515. Upon condensation, the distillates split into a lighter (hexane-rich) liquid with composition x_{Lg}=0.31 and a heavier (methanol-rich) liquid with composition x_{Hv}=0.743. Such phase separation is carried out in the decanter. All the concentrations are in a (methanol) molar basis. As the feed composition is z=0.20, which is on the left side of the heteroazeotrope, the column where the feed enters will produce pure n-hexane. Based on such interpretation, Fig. 1**b** shows the flow diagram used in the enhanced distillation of the methanol/n-hexane mixture using Aspen Plus.

With this idea in mind, it results evident the need for some previous training on the interpretation of phase diagrams before the students first deal with simulations by their own (assigned Aspen Plus case studies). Over the past years, the students were found to have serious problems with setting up the blocks and streams, and assigning correct variable values. The students failed at interpreting the phase equilibrium diagram. By way of example, for a given feed composition, they should be able to identify: a) whether a pure component leaves the column as overhead or bottom product; b) whether the feed enter the low or the high pressure column, in the case of PSD; c) whether the feed can enter both the column and the decanter or only the column, in the case of BHD; d) which pure component will be separated in each of the two columns, etc.

3.2. The teaching strategy

Our experience, which is part of a formative assessment strategy on mass transfer separations, was based on the Quizizz app. The reasons behind our choice among the all other available platforms (Table 1) were, mainly, two: i) its highly appealing interface; ii) it is less popular than others like Socrative or Kahoot!, thereby it may attract the interest of a larger number of readers within the Chemical Engineering educational community. Such a feature offers a broad scope for research.

Quizizz helped create a learning environment in which the study of phase equilibrium diagrams took place more pleasantly. Autonomous learning was stimulated through a flipped classroom approach, which was enhanced by the integration of gamification.

The total number of students who participated in the experience was 19: 10 in 2021–22 and 9 in 2022–23. The reason behind such a low number is that the activity being the matter of this study is part of a formative evaluation strategy, not followed by the whole class (the remaining students choose summative evaluation, merely based on a final exam). Even so, such small group had the advantage of facilitating the learning process.

Before the experience got started, the students were asked to complete a form, made available through a link to Google Forms, with 10 questions aimed to find out about their previous learning experiences

Table 2
Content blocks and distribution of teaching hours for the course "Advanced analysis and design of mass transfer separation operations".

CONTENT BLOCKS	Lectures & problem solving workshops (hours)	Computer lab sessions (hours)
i) Multicomponent rectification	10	7.5
CASE i.1. Key components and composition profiles		2.5
CASE i.2. Optimization and limiting conditions		2.5
CASE i.3. Direct and indirect distillation sequences		2.5
i) Enhanced distillation	2	7.5
CASE ii.1. Pressure Swing Distillation		2.5
CASE ii.2. Binary Heteroazeotropic Distillation		2.5
CASE ii.3. Extractive Distillation		2.5
i) Humidification and cooling towers	8	0
i) Adsorption	8	0
v) Membrane technology	12	0
v) Technical seminar*	5	0
	45	**15**

* Instructed by a Chemical Engineer working in a petroleum refinery located in the province of Huelva (Spain)

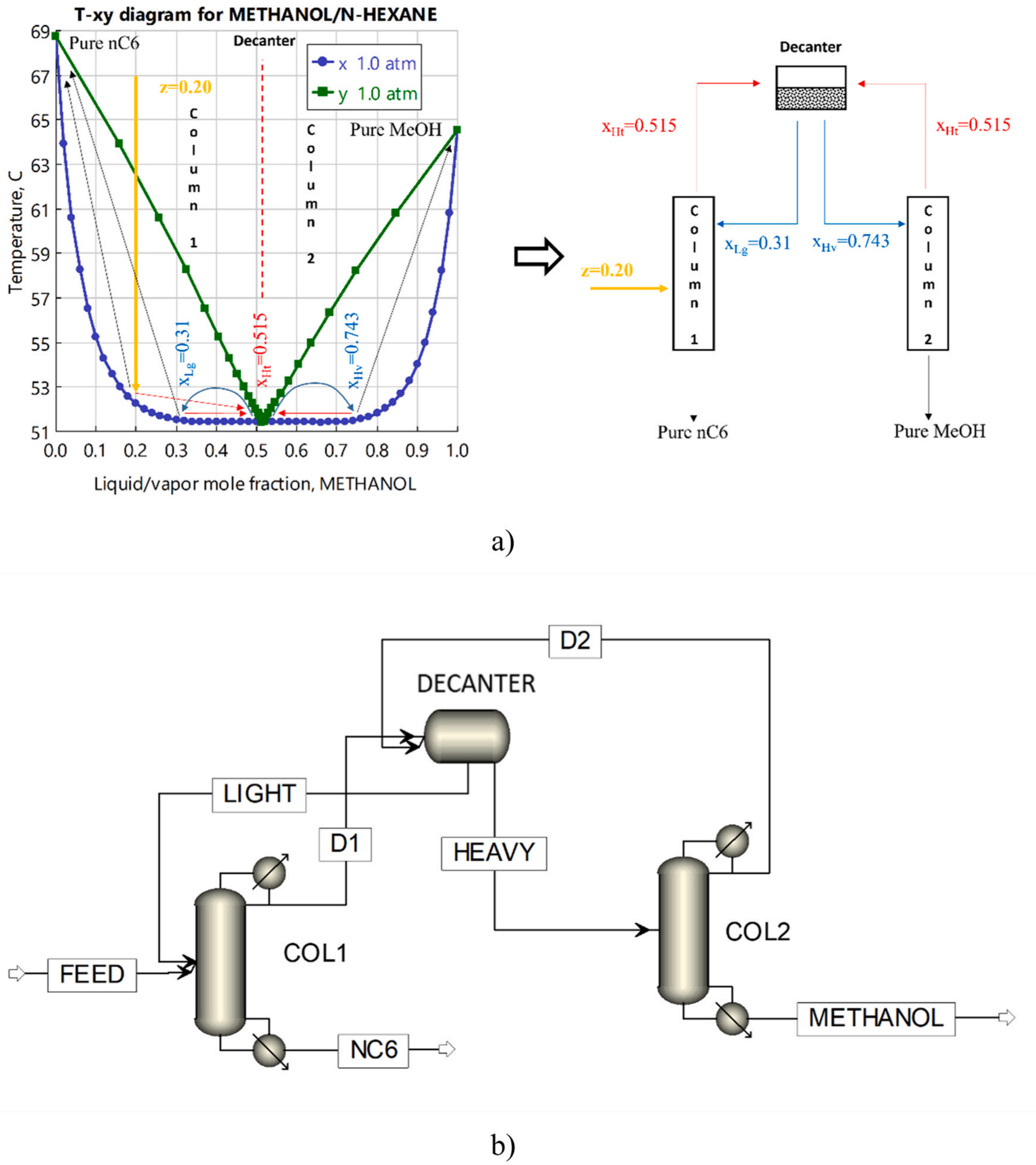


Fig. 1. a) Analysis of the methanol/n-hexane VLLE diagram and proposed complex separation scheme; b) Flow diagram illustrating the enhanced distillation of the methanol/n-hexane mixture using Aspen Plus.

using flipped classroom methodology and their opinion on the integration of the Quizizz app into their learning process (later shown in Table 4). The students had to rate every item on a Likert-type scale of 1 (totally disagree) to 5 (totally agree). A box was also provided for the students to enter any additional information, although writing text on this box was not compulsory. The results of this questionnaire are reported in the next section.

Regarding the learning strategy, the class was divided into two groups with approximately the same number of students. Each group was assigned a distillation method. “Pressure Swing Distillation” (PSD) and “Binary Heterogeneous Distillation” (BHD) were chosen among the different enhanced (complex) distillation methods studied. The PSD/BHD distribution was 6/4 in 2021–22 and 4/5 in 2022–23. Dividing the class into two groups allowed us to compare the performance of the same group on a specific topic (either PSD or BHD) before and after the proposed methodology, and also to compare with a group which had not followed the methodology. Unlike azeotropic and extractive distillations, such chosen methods have in common that fractionation of the binary mixture takes place without addition of a third component (Luyben, 2012; Wankat, 2017). In both cases, PSD and BHD, the students need to interpret a phase equilibrium diagram before they can propose a feasible separation scheme.

Materials were prepared by the lecturers to facilitate the comprehension of the fundamentals. They consisted of four-page self-created documents with detailed explanation of both types of distillation processes, illustrated by their corresponding phase equilibrium and process flow diagrams. The materials were made available, well in advance, to all students (both groups) through the Moodle platform. The students were asked to read the materials at home before the day chosen to complete the Quizizz tests.

On the day of the Quizizz tests, in the classroom, the students were provided with the link (https://quizizz.com/join) and code to access a test on their own mobile phone. Each test had 10 multiple choice questions, with 4 possible answers each (only one answer was correct).

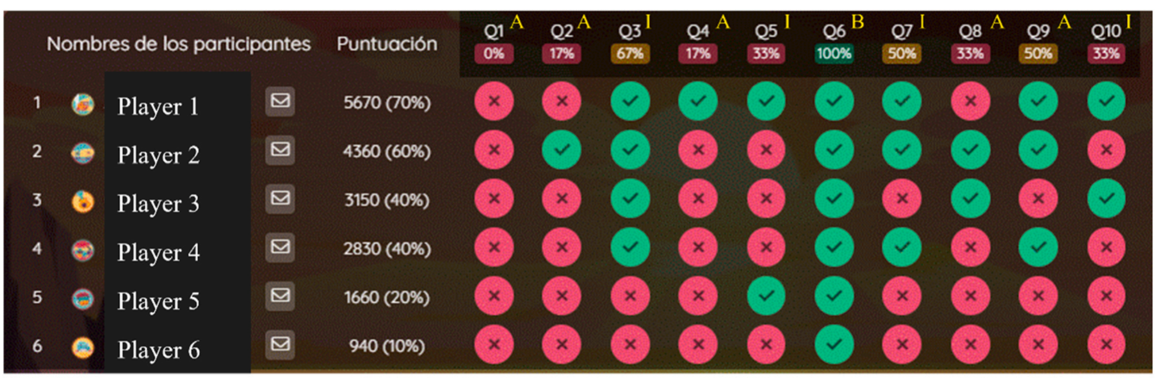
Each question was illustrated with a figure, showing either a phase equilibrium diagram or a process diagram. As reported by Moreno-Medina et al. (2023), this is intended to favor a more visual environment, which captures the students' attention more easily and quickly. The students had to interpret the diagrams before choosing the correct answer. The tests (PSD and BHD) are provided as supplementary material (download).

A gamification environment was assured by letting the students visualize, in real time, their own and their colleagues' results on the classroom screen. The lecturers made their best to promote a spirit of healthy competition, a concept that is understood as a short activity which has to be focused on the process rather than on the outcomes (Shindler, 2007). The PSD group participated in the first place. Meanwhile, the BHD group just played the role of mere spectators Once the PSD group finished, the BHD group took over. The Quizizz app assigns a fixed score of 600 points per right answer, plus up to 400 points per right answer depending on how fast the student answers, in a time interval of 1 minute. For the sake of encouraging the students to perform at their highest possible level, the students with the first, second and third highest scores were rewarded with bonus of 0.75, 0.50 and 0.25 points to be added to their overall grade (on a scale from 0 to 10 points), as long as they had got, at least, 6 correct answers.

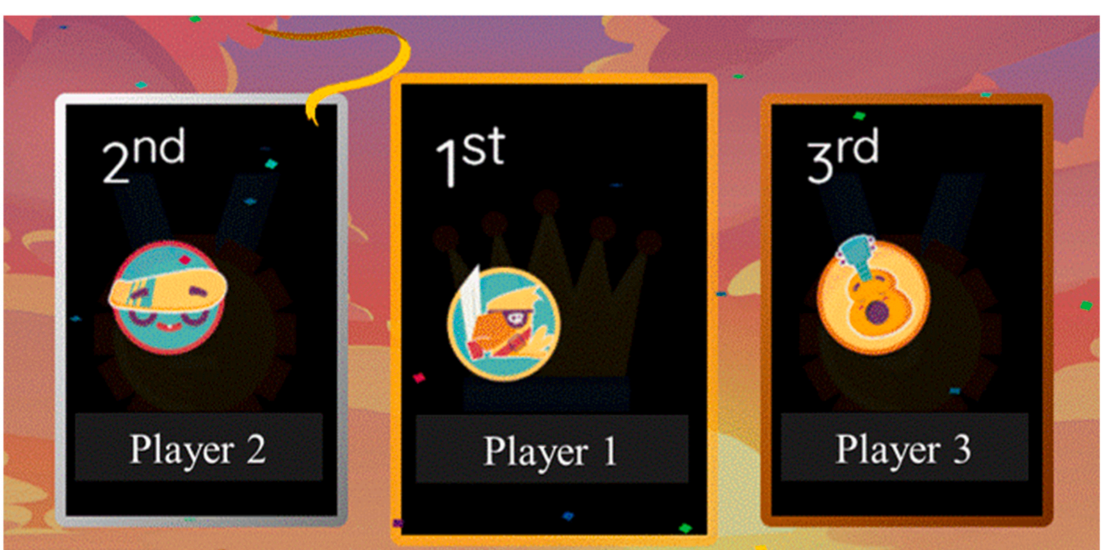
By way of example, Fig. 2**a** illustrates the PSD group results, in terms of final score and percentage of correct answers. It is noteworthy that the ten questions have been classified according to their level of difficulty as follows: B (basic), I (intermediate) and A (advanced). Further discussion on this issue is provided below in 4.3. Displaying time used in answering each question is also an option available. Fig. 2**b** shows the three best players. For the sake of respecting student privacy, their real names are not disclosed.

Upon finalization of both quizzes, the lecturers reviewed every question with the whole class, placing especial emphasis on those which the students most failed. Explanations were provided such that the students were taught to discard some answers and discern more easily between two a priori potentially correct answers.

The students were encouraged to revise again all the materials and tests by their own at home. On the following day, all the students (both PSD and BHD groups) were asked to complete a final test which served to look into the knowledge gained on the interpretation of complex phase diagrams. The test had 20 multiple choice questions (10 PSD questions and 10 BHD questions, randomly distributed) with the same level of difficulty as those used in the previous Quizizz tests. The test was made available through a link to Google Forms. The test took 20 minutes. A grade was assigned on a scale between 0 and 10 points. This final test represented 5 % relative to the student overall grade (Table 3). On completion of this activity, the students should have gained a deeper understanding on the phase equilibrium diagrams involving homogeneous/heterogeneous azeotropic mixtures, such that



a)



b)

Fig. 2. Academic year 2021–22, PSD group: a) Quizizz test results b) three best players.

Table 3
Evaluation items.

Item	Description	Tool	Weight
PSD/HBD final test	Interpretation of azeotropic phase diagrams	Google Forms	5 %
Aspen Plus activity	Case study on advanced distillation schemes	Aspen Plus	15 %
	Video-report on the proposed schemes	MS Power Point	10 %
Final exam	Numerical problems on the content blocks i), iii), iv) and v)	MS Excel	70 %

they are more skilled to propose feasible distillation routes. The remaining evaluation items (beyond the scope of this paper) which were used in our formative assessment evaluation are gathered and explained in Table 3. It is worth highlighting that the final exam is entirely solved using a MS Excel spreadsheet (Roman et al., 2021b).

Finally, the students were asked to complete another survey, made also available through a link to Google Forms, with 12 questions aimed to find out about their level of satisfaction with the herein reported experience (Table 5). The students had to rate every item on a Likert-type scale of 1 (totally disagree) to 5 (totally agree). A box was once again provided for the students to enter any additional information. This time, writing text on this box was compulsory. The results of this questionnaire are also reported in the next section.

4. Results and discussion

4.1. Students' previous experience

Information on the students' previous learning experiences was collected through the survey shown in Table 4. The results are displayed as average value ± standard deviation, on a scale from 1 (totally disagree) to 5 (totally agree).

In general terms, the survey yielded the following results:

- The students seem to have heard about learning methodologies such as "flipped classroom", "gamification" and "mobile learning", although their use in the classroom has only been moderate.
- Previous similar learning experiences involved the use of the very popular Socrative and/or Kahoot! apps, but Quizizz seems to be quite unknown yet.
- The students, who (apart from leisure) also use their smartphones for learning, think that mobile apps make the classes more enjoyable.
- The students are willing to make an extra effort at home if they are rewarded in their overall assessment.

Table 4
Students' pre-survey.

	Average	s.d.
1. The concept of "flipped classroom" is familiar to me	3.10	1.37
2. In previous years, some of my teachers have used the flipped classroom methodology	2.40	1.11
3. In the daily life, I am fond of using mobile apps for learning purposes	3.50	1.20
4. I would work harder at home if I could get extra points on a classroom competition	4.10	1.14
5. The concept of "gamification" is familiar to me	3.10	1.37
6. In previous years, I have used Socrative or/and Kahoot! apps in the classroom	4.00	1.26
7. Mobile apps can make the classes more enjoyable	4.20	0.87
8. The concept of "mobile learning" is familiar to me	3.70	1.00
9. Most of my teachers make use of mobile apps in the classroom	1.80	0.98
10. In previous years, I have used Quizizz app in the classroom	1.70	1.19

4.2. Impact on the learning process. Academic performance

Regarding the Quizizz (competition) test, the percentages of correct answers for PDS and BHD tests differed noticeably between the two academic years during which the experience was carried out: i) academic year 2021–22, 40 % and 55 %, respectively; ii) academic year 2022–23, 66 % and 76 %, respectively. This result is probably due to the different intrinsic learning capability (and/or access background profile) of the students. In any case, BHD groups performed noticeably better than PDS groups. An explanation will be provided in next Section 4.3, based on the type of equilibrium diagrams involved.

In order to analyze whether the reviewing session between the Quizizz test and final (Google-based) test had effect on improving the comprehension of the contents, the final test scores were plotted versus the Quizizz test scores, for each participant, in Fig. 3**a**. Obviously, the final test scores shown in Fig. 3**a** correspond to the 10 questions of the assigned topic (either PDS or BHD), and not the whole set of 20 questions. The diagonal and quadrants were plotted for the sake of reference. It can be observed that 12 out of 19 students improved their scores (some of them very remarkably) after the contents were explained in the classroom by the lecturer (above the diagonal), whereas 1/19 performed at the same level and 6 performed slightly worse. Thus, it seems that the lecture helped clarify the concepts and reinforced understanding. As for the "flipped classroom" implication, 13 out of 19 students were able, by their own work at home, to achieve at least 5 over 10 points in the Quizizz competition (1st and 4th quadrants).

In order to look further into the students learning process, Fig. 3**b** displays a comparative evaluation between the score the students reached in the 10 PSD questions of their final test as compared to the 10 BHD questions of the same test. The diagonal and the quadrants were plotted for the sake of reference. Regarding the PSD groups, 5 out of 10 students performed better in the PSD questions, the topic they were initially assigned (above the diagonal), whereas 2/10 performed at the same level and 3/10 performed slightly worse. As for the BHD groups, 5 out of 9 students performed better in the BHD questions, the topic they were initially assigned (1/9 performed at the same level and 3/9 performed worse). Hence, in general terms, we might conclude that the students' scores had a direct relation with their initially assigned contents. Moreover, 13 out of 19 students achieved at least 5 over 10 points in both test (1st quadrant), whereas 18 out of 19 students achieved at least 5 over 10 points in at least one of the tests (1st, 2nd and 4th quadrants). In any case, it is evident that the students understood reasonably well the contents.

By reading the materials provided by the lecturer before the class, the students got started in the study of the contents. Our own impression is that most of the students read the materials most probably because they were brief, got straight to the point, and contained a lot of illustrations. Apart from the introduction of technology, another key element of the strategy was the reviewing session, focused basically on clarifying the fundamentals through the analysis of wrong answers, and providing the students with guidance on how identify more easily the right answers. In this way, the students achieved a much deeper understanding on how to interpret phase equilibrium diagrams, as compared to the method based on the traditional master-class, when the interaction students-teacher was almost non-existent and their understanding was only superficial. This is evidenced by the results shown in Fig. 4, which displays the students' performance, in terms of their ability to solve their assigned Aspen Plus case study (evaluation item displayed in Table 3). A 4-year period, from 2019-20 to 2022-23, was envisaged aimed to establish a comparative analysis. As explained above, during 2021–22 and 2022–23 the students followed the reported methodology based on flipped classroom assisted by tech-enhanced gamification (Quizizz competition) before doing their Aspen Plus assignments. In contrast, during 2019–20 and 2020–21 the students just received a master class, so these have been used as "control" groups. In order to minimize the potential for bias due to the intrinsic learning skills of each group when solving their

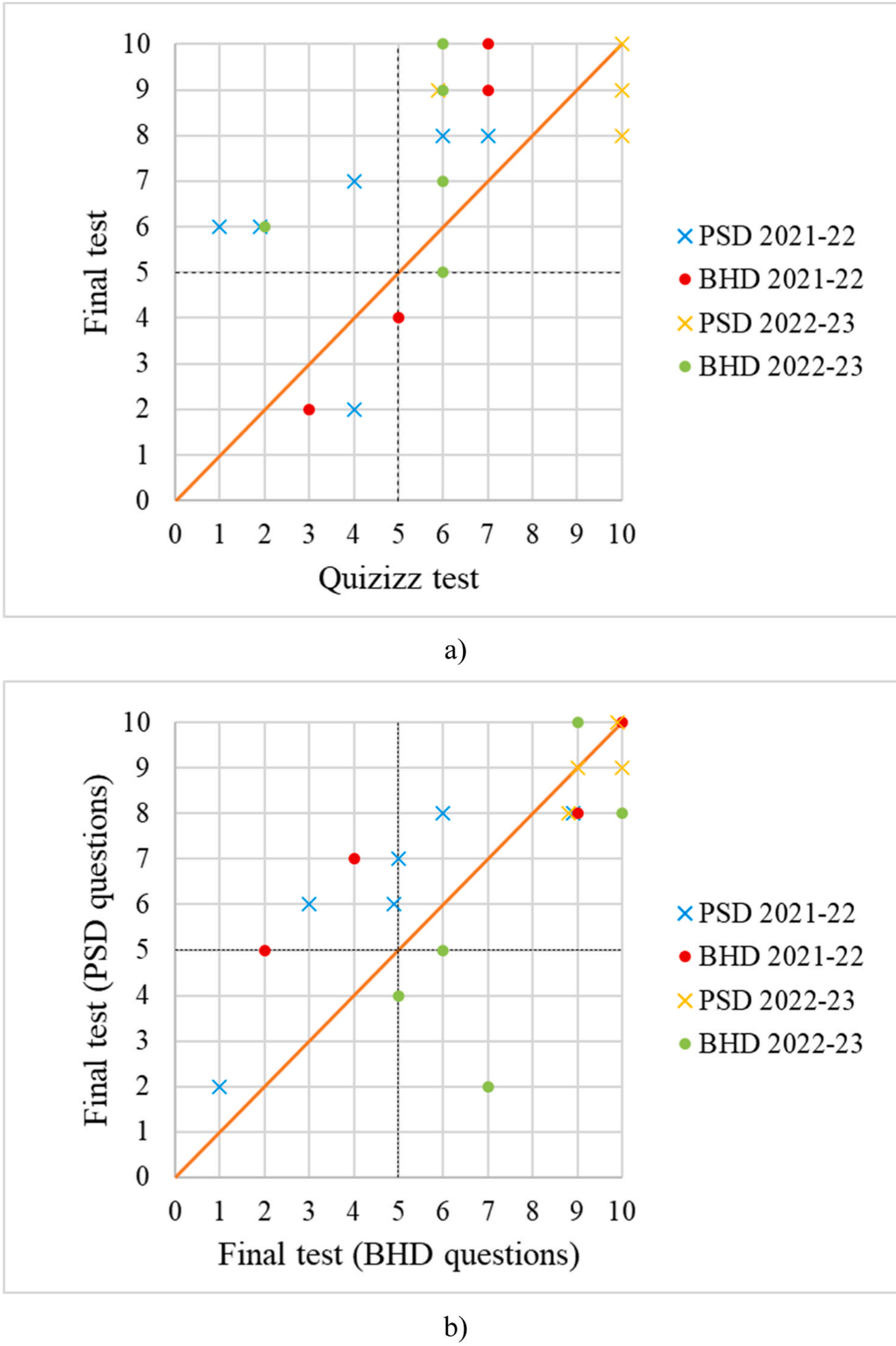


Fig. 3. Comparative evaluation of performances: a) before (Quizizz test) and after (final test) the reviewing session; b) in final test, PSD vs. BHD.

Aspen Plus assignments, relativized results are presented in Fig. 4. Hence, the ratio of Aspen Plus case study score relative to the final exam score (both of them are evaluation items displayed in Table 3) has been used with the purpose of comparison.

4.3. Learning outcomes and limitations

Obviously, interpreting the diagrams is not as straightforward as memorizing definitions. Therefore, the process implies training. This is the reason why the gamification activity and the reviewing session were planned before the final evaluation test. Analyzing helps students understand the information on a deeper level whilst memorizing merely allows touching the surface. In Bloom's taxonomy, the cognitive domain is broken into the six levels of objectives (Adams, 2015). Quizizz tests (diagram interpretation) and case studies (building up separation schemes accordingly), provided in supplementary materials, relate to level 3 Analyze and level 6 Create, respectively, thereby, high order thinking skills (HOTS). In contrast, let's think of a hypothetical alternative question such as "*How does pressure swing distillation work? a) Two columns in series at same pressure; b) Two columns in parallel at same pressure; c) Two columns in series at different pressures; d) Two columns in parallel at different pressures*". This type of question would correspond to level 1 Remember, i.e. a low order thinking skill (LOTS). Multiple choice question quizzes have traditionally been considered to have very limited

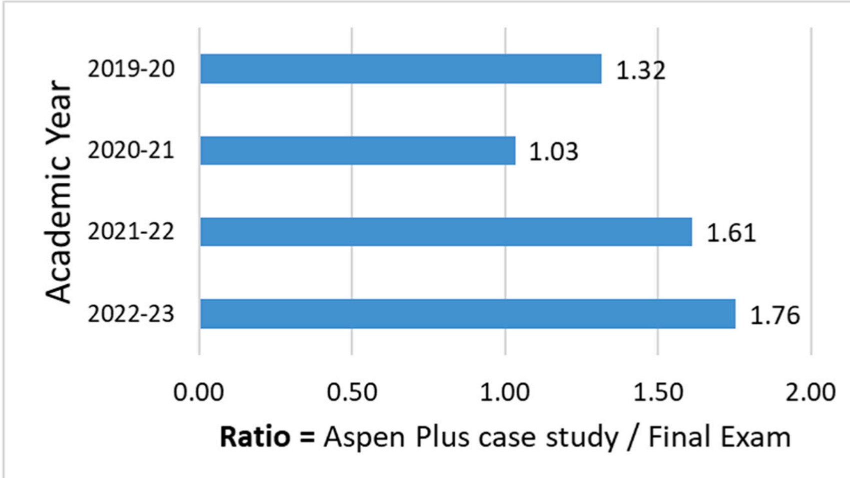


Fig. 4. Comparative evaluation of performance during the 4-year period 2019-20 to 2022-23 (2019–20 and 2020–21 are "control" groups).

scope to engage students in reflection and evaluative judgement (Ravi, 2023). However, the questions can be formulated in a way that contextualize real ChE scenarios, with different level of difficulties, therefore testing higher order cognitive skills (Caserta et al., 2021).

In that sense, Fig. 5 gives examples of three selected questions corresponding to the PSD Quizizz test. As shown in previous Fig. 2**a**, everyone responded correctly the sixth (basic level) question (Fig. 5**a**), whereas no-one was able to give the right answer to the first (advanced level) question. In between, 33 % students failed the third (intermediate level) question. The issue is worth analyzing. With regard to Fig. 5**a**, it results very simple to identify a minimum boiling azeotrope if the question is illustrated using a flow diagram on which pure components are recovered as bottom streams. Moreover, Fig. 5**b** also seems to be quite clarifying, as the minimum boiling azeotrope is displayed in the form of Txy diagram. In that sense, such azeotrope is attained at smaller temperature than either of the pure components. In contrast, the typical McCabe-Thiele distillation diagram (Fig. 5**c**) seems to cause more confusion because the information contained is somehow "hidden". Therefore, its interpretation in terms of the correct identification of minimum or maximum boiling azeotropes (Luyben, 2012) requires a great deal of concentration and abstract thinking skills.

In relation with the previous statement, it is noteworthy the fact that both in 2021–22 and 2022-23 the ratio BHD to PSD in terms of % of correct answers was significantly higher than 1, therefore, proving that BHD contents were more easily assimilated than PSD contents. As shown in Fig. 6, BHD separation is merely based on a single equilibrium curve, as compared to PSD separation which requires the simultaneous interpretation of two curves at different pressures.

The method still has scope for improvement. We would suggest preparing audiovisual materials on general contents, and with supplementary information containing some examples of how to identify correct answers. The main drawback is that the method requires the preparation of many materials, thus it is a lot of work for the teacher.

As previously mentioned, the chosen course was very well suited for this type of learning experiences given that the small group of students facilitated their involvement. Even so, it is fair to admit that this aspect might represent a limitation of the study in terms of sample size. However, the present experience was intended to pave the way for more research in the future, and was enough to perceive that the students made very remarkable progress as long as interpretation of VLE and VLLE diagrams is concerned.

4.4. Students' satisfaction

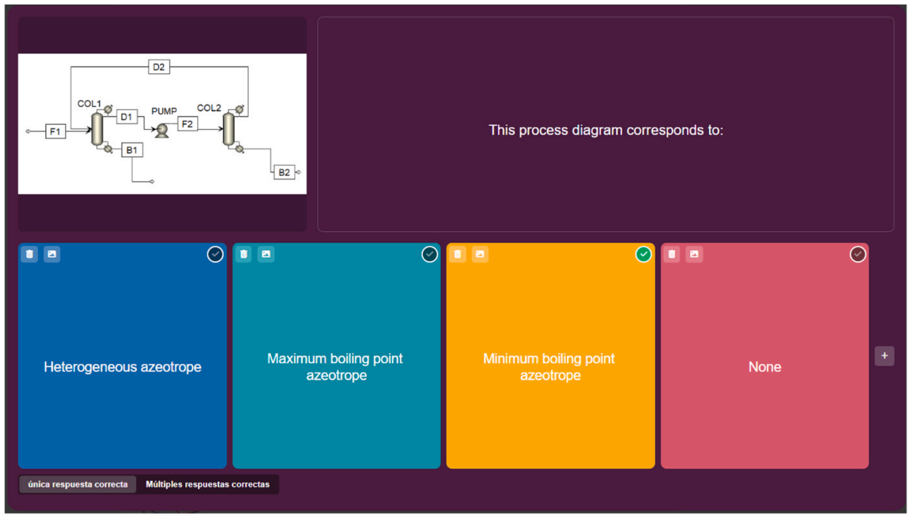
Upon finalization of the activity, the students had to complete a second survey on their level of satisfaction with the activity (Table 5). The results are shown as average value ± standard deviation, on a scale from 1 (totally disagree) to 5 (totally agree).

In general terms, the survey yielded the following results:

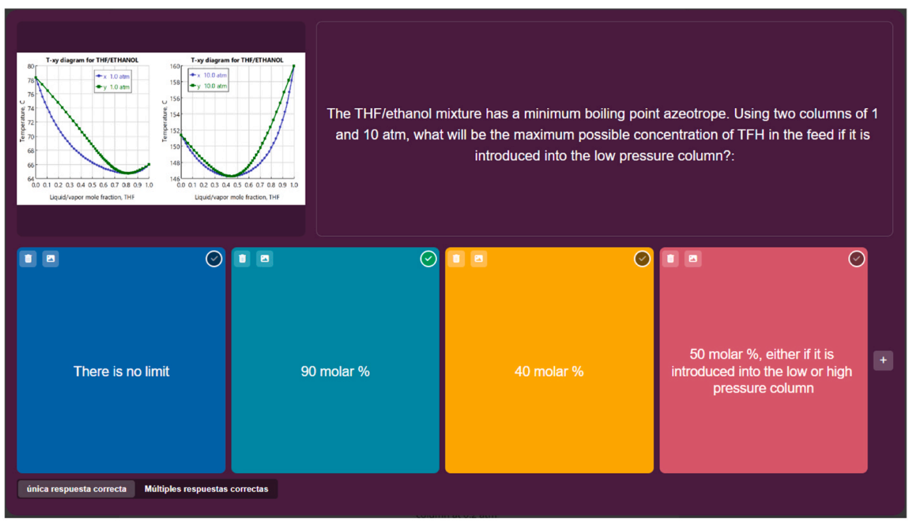
- It seems that the materials were clear enough such that the students were able to interpret the phase equilibrium diagrams by themselves.
- The competition using the app engaged the students more than a traditional lecture.
- The students were satisfied with the way the teacher had designed the activity, most probably because it was an efficient method of learning complex distillation as compared to previous years when the contents were addressed in a standard master-class.
- Most of the students agreed that the methodology is valid for other courses within their study program.
- Most of the students also admitted that the reviewing class focused on clarifying the fundamentals through the analysis of wrong answers. That, along with the use of mobile learning, is probably the decisive factor.
- It seems that a significant fraction of the students only read the materials related to their assigned topic, i.e. <u>it was the competition that really strengthened the student's autonomous work</u>.

Some feedback was received from the students. There were controversial comments regarding the time available to answer the questions. Some think that taking the test under that pressure led to avoidable errors, whereas others saw it as an opportunity to put into practice their ability to make quick decisions and their "creative thinking". Controversial responses were also found in the sense that some believe that such a competition environment made them give their best. Others, on the contrary, think that "it is demotivating to see, in public, that your classmates do it better than you". In fact, as far as question 7 in Table 5 is concerned, we cannot conclude that it was the reward that really motivated the students. It might be that they did not want to feel ashamed of being the last classified. Whether classroom competition is good or bad has always been a matter of debate (Kristensen et al., 2015). Cantador and Conde (2010) reported that competition may boost student motivation and academic performance if a number of principles (symbolic or little value prize, a short duration, and a goal clearly set into the learning process) are followed. In that sense, we conclude that our experience adhered to such guidelines.

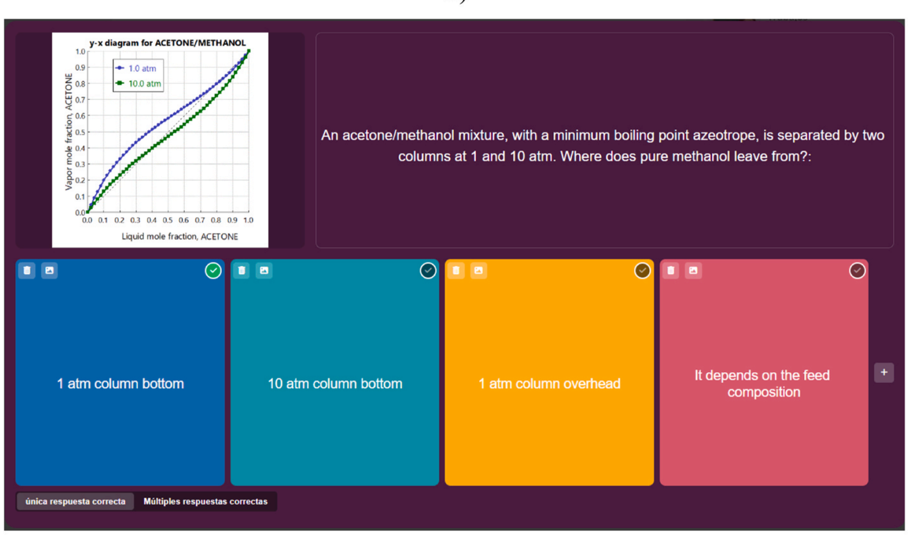
In general terms, the activity was mostly referred to as "a lot fun" or



a)



b)



c)

Fig. 5. Selected questions from the PSD Quizizz test: a) Q6; b) Q3; c) Q1.

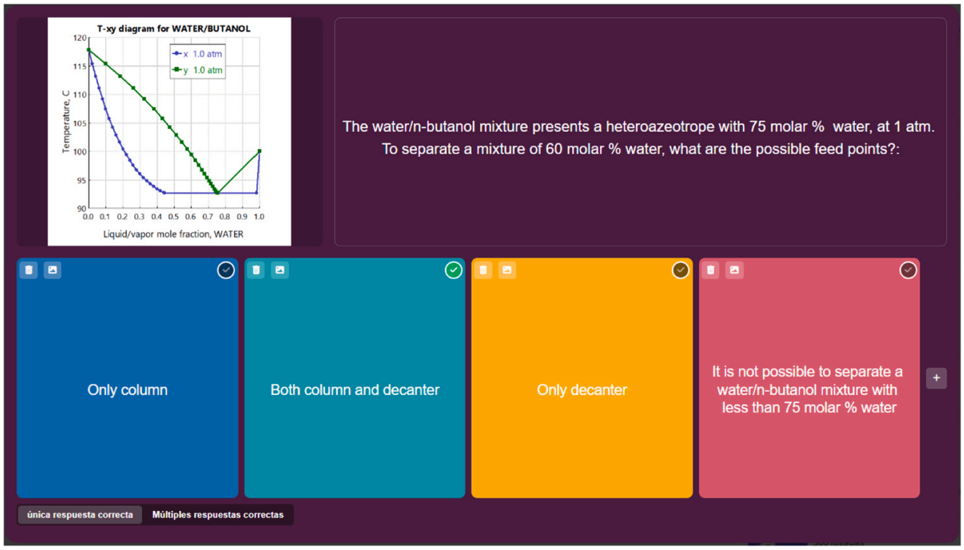


Fig. 6. Selected question, Q1, from the BHD Quizizz test.

Table 5
Students' post-survey.

	Average	s.d.
1. Reading the materials provided by the teachers before the class helped me better understand the contents	3.89	1.17
2. I revised both materials (related to the topic I was assigned and the topic I was not)	3.44	1.74
3. Reading the materials provided by the teachers took me too much time	2.11	1.05
4. The reviewing class focused on clarifying the wrong answers from the Quizizz test	4.44	0.88
5. The Quizizz competition was more fun than a standard test	4.78	0.67
6. The teachers rewarded the students who performed better in the Quizizz competition	4.67	0.50
7. Such a reward encouraged me to read the materials at home	3.67	1.00
8. The activity grade was considered in the course overall assessment	4.44	0.53
9. The activity was well-planned and well-integrated into the course	4.33	0.71
10. It was the first time I have participated in something like this	3.33	1.87
11. The methodology used can be applied to other subjects	4.67	0.71
12. Overall rate of the experience	4.44	0.88

"entertaining", and was considered a good alternative to the traditional class. One of the students stated that "the contents were clear and easy to understand", whereas another student said "I would have preferred more time to review the test solutions with the teachers".

5. Conclusions

The reported experience was carried out, with promising results, in a Mass Transfer Operations course within a Chemical Engineering Master's degree program.

In our opinion, applying the method to enhanced distillation was a good choice, because it yielded a better understanding of the phase equilibrium diagrams that enabled the students to propose suited separation schemes. Hence, their Aspen Plus assignment results improved as compared to control groups which had not enjoyed the proposed methodology. Survey results evidenced the quite limited use of the Quizizz app in previous courses, although it has features which make it a more appealing option than Socrative or Kahoot! In that sense, a visual examination of the classroom environment enabled to conclude that the method, in general, and the tech-assisted gamification stage, in particular, strengthened the students' engagement, encouraging them to work harder at home and to participate more actively in the classroom. However, it is worth emphasizing that the method only yields efficient learning when it is well organized, in terms of properly selected questions and including a suited reviewing session.

Compliance with ethical standards

the research did not involve neither human participants nor animals

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CRediT authorship contribution statement

Miguel Ángel Delgado: Conceptualization, Investigation, Methodology, Software, Writing – review & editing. **Moisés García-Morales:** Conceptualization, Data curation, Investigation, Methodology, Project administration, Software, Supervision, Validation, Writing – original draft, Writing – review & editing. **Claudia Roman:** Conceptualization, Investigation, Methodology, Software, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ece.2024.11.001.

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