

Article

Assessment: A Suggested Strategy for Learning Chemical Equilibrium

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Abstract: Chemical equilibrium is listed as one of the most complicated concepts to learn, and the origin of this phenomenon is attributed to misconceptions, teaching-related problems, and the use of inappropriate didactic approaches. At the same time, assessment is a crucial fragment of educational activities although its relevance as a learning strategy is underestimated. For that reason, we designed and applied unique assessment approaches related to chemical equilibrium to 33 high school students at *Colegio Mayor de San Bartolome* (Bogotá, Colombia). The results suggested that assessment instruments focused on the identified misconceptions might reduce the impact (of the misconceptions), and students were able to build concepts related to chemical equilibrium whilst they were being assessed. Problems associated with forward and reverse reactions, differences between initial and equilibrium concentrations, and the indiscriminate use of Le Chatelier's principle were approached by students and significant improvement was achieved through the assessment. Changes associated with assessment perceptions were accomplished and the proposed strategy suggests that it is plausible to learn during the assessment moment.

Keywords: assessment; chemical equilibrium; learning; misconceptions

1. Introduction

1.1. Didactics of Chemical Equilibrium

A plethora of publications related to the didactics of chemical equilibrium have emerged in the last decades as a consequence of several reasons including: misconceptions, lack of understanding, overlapping of the macroscopic and microscopic representation levels that usually occur in teaching [1–8], and its abstract nature [9,10]. Furthermore, chemical equilibrium is considered as a complex and counterintuitive concept, and its learning is compromised by common alternative conceptions [11], as well as the large number of subordinate concepts [12,13]. There are even reports describing that students have experienced difficulties with the basic concepts of algebra, nomenclature, and stoichiometry during the process of learning chemical equilibrium [14–16]. Other authors, however, have centered their attention on the way that the concepts are taught [16,17]. Most of the time these difficulties are not spontaneous ideas but they are induced through teaching [18]. Indeed, teachers are generally weak on this subject [19,20], which is another factor that affects the learning process.

For these reasons, the introduction of chemical equilibrium requires a scrupulous revision of the related concepts [21,22].

Several strategies have been proposed to facilitate the learning of chemical equilibrium. Amongst them, the need for a methodological change about how to teach it [23,24], a comprehensive analysis of

misconceptions [10,19,25,26], and the identification of the persistence of errors [9,27], can be mentioned. Nonetheless, the elaboration of instructional materials for teaching this topic has been considered by some researchers, although few innovations in terms of teaching methodologies and classrooms dynamics have been consolidated [22,28]. Thus, strategies in which assessment is considered as a tool to facilitate the learning of chemical equilibrium do not appear with sufficient importance in scientific literature. Despite its relevance, there is still an unexplored niche in the didactics of the natural sciences research field.

1.2. Assessment

Several distinctions have emerged over the last decades regarding the purpose of assessments. Formative assessment provides feedback and correctives at each stage in the teaching–learning process; summative assessment is employed to judge what the learner has achieved at the end of a course [29]; and diagnostic assessment provides learners with the opportunity to develop a more comprehensive understanding of the concepts [30].

Significant emphasis has been placed on using alternative assessments, such as performance assessments and portfolios, rather than on traditional paper-and-pencil assessments [31]. In this context, assessment is acknowledged as the center of student learning experiences and it has been reported that the quality of the assessment influences the learning. Besides, assessments help students to gain insight into their progress, thereby supporting appropriate engagement and learning, as well as promoting higher cognitive competences [5,32,33].

The assessment could be considered as one of the most important activities in educational work. However, general assessment practices in chemistry do not require students to express their ideas in writing using an extended-response format, such as essay answers or term papers [34]. In this matter, formative assessment has gained significance, although it is misunderstood across higher education [35].

Recent research claims that there is no acceptable purpose for educational assessment other than to improve student learning. Within this frame, formative assessment is designed to directly improve student learning. While there is growing agreement that formative assessments should be an equal component with the curriculum, empirical evidence on the efficacy of formative assessments is lacking. More research regarding proper use of formative assessment is needed [36].

In disciplines such as chemistry, it has been observed that the majority of evaluative practices (95.2%) encourage repetitive learning and that teachers are not aware of this fact [37]. Moreover, teachers and students generally see assessment as a synonym for grading. This background supports the idea that assessment in scientific disciplines is an objective process, and it is normal that a high percentage of students fail [38]. Indeed, it has been shown that teachers are implementing a narrow interpretation of formative assessment, and that classroom practices are still dominated by summative assessment procedures designed to assure that students comply with the criteria [39].

Chemical equilibrium is normally evaluated in a traditional way (pencil-and-paper problems), [40], and a further analysis of these evaluation methods confirms the presence of misconceptions and indicates that educational assessment is considered as the final part of the teaching–learning process, not as a learning strategy [41]. For a significant majority of science teachers, the assessment's primary aim is to measure the student's capability, and grade them as an objective base for promotion and selection. Often, tests do not contain the potential for discovering the weak and problematic conceptualizations, and thus, do not normally provide teachers with feedback on the effectiveness of their instruction [42]. Consequently, there is an intimate relation in which subjects such as chemistry are easy to objectively evaluate, because of the nature of the evaluated concepts.

Assessment is an integral component of the teaching and learning process, and its impact goes further than being a means of assigning a grade [43]. Traditionally, terms such as testing (test), examining (examinations), and grading (grades), were used in the context of general education. However, in the early 1970s, the term assessment came to be generally associated with these activities. Before that,

the term assessment seemed to have been associated with individuals, and it was sometimes specifically associated with judgments about children who had specific learning and/or other needs [44,45].

Although the concept of using assessments to identify difficulties in learning and to support growth in learning has been embraced in many countries across the world, there is considerable diversity in how the assessment is translated into practice, as well as conflicting views about how it is defined [46]. In this matter, teachers, researchers, epistemologists, philosophers, and other experts related to the educative system have proposed assessment strategies [47–49]. Thus, all the aforementioned experts might consider that an assessment is probably one of the most important activities that teachers can perform to help students to learn. Moreover, there is a close relationship between teachers' assessment methods and the way students learn. Indeed, assessments should provide some description of a student's level of attainment in all aspects of the course, to diagnose strengths and weaknesses, to identify misconceptions, and to help to plan the further learning of each student [50]. Assessment practices, both good and bad, affect student engagement with learning. Thus, assessment has a significant impact on all aspects of the students' experiences, satisfaction, outcomes, and success [51].

Theoretical models have been proposed to elucidate the effects of assessment on the learning process, and it has become clear that assessment affects learning before, during, and after the assessment activity [52]. It is clear that any modification to the assessment practices will have repercussions on both students' attitudes and learning.

As the assessment is a crucial component of the learning process, assessment for learning has emerged and it encourages students to keep learning and remain confident that they can continue learning at productive levels [53]. Moreover, it needs to be enclosed into the theoretical frameworks of meaningful learning [54] and conceptual change [55,56]. Indeed, by the specificity of this work, we also considered the Ignatian Pedagogical Paradigm (IPP) [57].

1.3. Meaningful Learning and Conceptual Change

Ausubel and Novak brought a radical interpretation to the educational learning theory by introducing the term "meaningful learning", which occurs when new information is purposefully connected to a student's existing knowledge. Therefore, meaningful learning occurs when new information is linked with existing concepts. Within this context, Ausubel mentioned a famous sentence: "If I had to reduce all of educational psychology to just one principle, I would say this: The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly" [54].

To achieve meaningful learning, the student must have some relevant prior knowledge to which the new information can be related in a non-arbitrary manner; the student must consciously choose to non-arbitrarily incorporate this meaningful material into his/her existing knowledge; and the material to be learnt must be meaningful [58–60].

Four steps of the meaningful learning theory have been recognized: Identify the students' knowledge; create opportunities for students to explore their ideas; provide stimuli for students to develop, modify, and where necessary, change their ideas and views; and support their attempts to re-think and reconstruct their ideas and views. Therefore, more effective learning activities should be developed to help students acquire meaningful learning in place of rote learning.

Since knowledge is a human construction, Novak believes that education must enable people to construct knowledge; that is, education should consist of experiences that will empower a person to manage his or her daily life. He classifies such experiences as occurring within either the cognitive, affective, or psychomotor domain [58].

The constructivist approach can be reinforced with conceptual change instruction, which lets students activate and modify their existing knowledge or misconceptions [61]. The construction of knowledge, therefore, depends on the interaction of personal experiences with private understandings [62], including the assessment practices.

Sometimes students use existing concepts to deal with new phenomena. Often, however, the students' current concepts are inadequate to allow him/her to grasp successfully some new phenomenon. Then the student must replace or reorganize his/her central concepts [55]. Nonetheless, whatever strategy a teacher uses, each student will construct their own meaning based on an interaction between prior knowledge and current learning experiences [63].

1.4. Ignatian Pedagogical Paradigm (IPP)

Although Jesuit education is framed into the spiritual dimension, its background is useful in the entire educative context. For that reason, the IPP indicates that learning should be situated in a specific **context** and rooted in previous **experience**. Then, the result of new learning depends on a **reflection** about these experiences. Furthermore, learning is meaningful when new knowledge is put into some kind of **action** and reinforced by explicit **evaluation** (and ultimately, self-evaluation) of these actions, and the degree to which learning has occurred [57,64]. Within this frame, evaluation measures more than intellectual success [64,65].

Despite the broad spectrum that Jesuit education in general and IPP in particular have in Catholic schools or institutions managed by Jesuits, it has been acknowledged that Jesuit education covers several disciplines in different contexts [66–69], including the educational one [70]. Thus, IPP can be considered as a versatile framework for overcoming issues related to the learning and teaching process.

1.5. Research Problem

This research designed assessment instruments for chemical equilibrium, which simultaneously, were instruments for learning based on IPP. The learning process was defined as a concept that involved the establishment of new and/or better significant conceptual structures which students were able to build; and that these constructions were significant for them. In other words, if assessment tools allow students to identify and improve concepts they possess around chemical equilibrium, or even better, if they can change these concepts with chemical sense, then there will be learning. Thus, assessment instruments (assessment) designed for learning (assessment for learning), and framed into a pedagogical proposal (IPP), might be considered as an innovative strategy for overcoming the reported problems that students exhibit during the process of teaching–learning chemical equilibrium.

2. Materials and Methods

2.1. Population

The target population was 130 students (4 courses) in grade 11 (16–17 years old) studying at *Colegio Mayor de San Bartolomé*, and the sample consisted of 33 students (one course) from both genders (27 masculine and 6 feminine). The study was classified as a qualitative and quasi-experimental design, and a one-group pretest-posttest design was used. The school approved the participation of the students and an informed assent was signed.

2.2. Instruments

During the research, eight instruments were designed and validated in terms of readability, clarity, internal coherence, and content by 25 experts (Table 1) enrolled in the 3rd year of chemistry at the *Universidad Pedagógica Nacional* (Bogotá, Colombia). Then, the instruments were presented to teachers of chemistry working in five schools in Bogotá, and the final adjustments were made.

Table 1. Instruments used during the research.

IPP Structure	Instrument
Context	Ideas about assessment (Appendix A) Previous knowledge (Appendix B)
Experience Reflection Action	Work guidelines
Evaluation	Chemical rate Relationship between reagents, products, and equilibrium constant (Appendix C) Assessment I Assessment II (Appendix D) New ideas about assessment

2.3. Didactic Strategy

Following the curricula and pedagogic frame of the institution in which the research was conducted, no modifications to normal activities were done during pedagogical intervention. In this matter, as the school was under Jesuit direction, the IPP was performed as in Reference [64]. Thus, five moments were planned, and educational activities framed in context, experience, reflection, action, and evaluation were carried out. Learning is focused on context. Experience is any activity that includes cognitive and affective situations. Reflection is the process by which meaning is articulated. Action relates to the choices made, whilst evaluation leads to another experience [71]. Therefore, after asking for previous ideas about chemical equilibrium, the students were encouraged to work on their learning activities. Finally, the assessment instruments were applied to identify new conceptual networks about chemical equilibrium that the students were able to build.

3. Results and Discussion

3.1. Previous Ideas about Assessment

Several pedagogic tendencies involve searching for modifications in assessment processes due to unpleasant feelings that students experience whilst they are being assessed. Within this framework, the first instrument (Appendix A) identified how students generally perceived the assessment in their chemistry classes. The sample was asked about the kind of feelings they experienced at the moment of being evaluated, and the results obtained are shown in Table 2.

Table 2. Feelings that students experienced during the assessment practices carried out in chemistry courses.

Option	Frequency	
	Before	After
Tranquility	9	18
Anguish	8	6
Anguish-Insecurity	5	0
Security	5	6
Insecurity	4	1
Security-Anguish	1	0
Tranquility-Insecurity	1	0
Security-Tranquility	0	2
TOTAL	33	33

Negative feelings prior to the test originated from the experiences that students had during their studies. It is common to consider that “exams” assess knowledge, and that the assessment is linked only to the moment of answering a test [72]. There has always been a misconception about evaluation, that is, it has been associated with the moment when an exam is taken. In other words, the act of evaluating is equivalent to the certification of knowledge that students have learnt and that professors have taught [73]. Moreover, the academic field characterizes stressful situations by virtue that people do

not have total control over the situation [74]. For that reason, the importance that the assessment has for students is undeniable [72], as well as the effort that assessments hold. Other studies have found that students perceived traditional assessments as arbitrary and irrelevant, and the process was not effective for learning [75]. As can be inferred, assessment exhibits a high probability for provoking stress because there is no chance to be prepared for it, and assessment-related stress can be associated with an “expected correct answer”, which indicates that the result is the important issue. For that reason, new assessment strategies are being considered in the scientific community where the main goal is not a grade (related to an activity), but the focus is centered on the student’s performance in learning activities [76].

Upon return of the corrected assessments to the students, a significant majority showed a higher interest in the grades, as well as in identifying mistakes in grading (Table 3). Nonetheless, cases of success failed to be examined, converse to failure analysis, which accounts for most pedagogical debates [3,4,77,78]. The results obtained suggested that assessment processes were perceived as the measurement of student quality/ability, instead of being considered as an opportunity for learning. In fact, it seemed that the main purpose of the assessment was to measure the acquired knowledge framed in the traditional assessment methods that emphasized memorization and factual recall of taught subjects [5], whilst just a few students pondered that the intention was to promote the learning process. For instance, one student mentioned that the grade was important because *I need to approve the subject, but if I fail, I check out the answers because I want to identify my mistakes, and it helps me to improve. I also check out my classmates’ answers.* Another student mentioned that *... I check out my grade always and my strength and difficulties. Then, my friends and me compare our results because I want to be sure about how to solve the problem* (texts were originally written in Spanish and translated and edited to English for this manuscript). It is worth indicating that this instrument showed that an assessment was not an activity that students might consider as a moment for learning, and furthermore it was an unpleasant and stressful activity. Since one of the major goals of the research was to promote learning during the assessment, we specifically designed further assessment instruments to reduce the tension that the activity might induce. This was achieved by modifying the traditional assessment methods.

Table 3. Actions that students do after getting their assessment results.

Options	Frequency
Query the grade and check out the answers	19
Compare the answers with others	5
Identify the questions with difficulties and compare	3
Query the grade and compare	3
Identify the questions with difficulties and rewrite them	2
Ignore the grade and review answers	1
TOTAL	33

Given the negative perception that the assessment had on the sample, it was predictable that the responsibility for the assessment practices relies on the teacher. The results evinced that tendency, and one third of the sample expressed this perception in that sense, which implied that learning processes corresponded to a transmission–reception model, and the assessment relied on the professional competence of the teacher [79]. For students, it is plausible to assume that the spirit of the assessment is to measure their capability to obtain a grade objectively [38]. Unexpectedly, two thirds of the sample manifested that the teacher and the student share the responsibility of the assessment.

It is worth mentioning that a majority of the sample expressed that the assessment could not be considered as a learning strategy, a position that is understandable under the paradigm in which students are generally educated. Moreover, the students’ perceptions about assessment are influenced by their own experiences, and the way they are evaluated.

It has been established that inappropriate forms of assessment, for example, measuring factual knowledge when understanding is the learning goal, can push students towards superficial approaches

to learning; whereas, high quality assessment with appropriate feedback can encourage students to get involved in the material and use a deep approach to learning [80]. Thus, the adverse impact that assessment has on learning does not mean that under certain conditions assessment holds considerable potential to enhance learning [32]. These conditions include that the assessment instrument needs to be specifically designed to promote learning, which in the frame of this research means that the student is able to use concepts to solve a problem situation with chemical sense. Therefore, the student learns a new concept such as chemical equilibrium.

3.2. Previous Ideas about Chemical Equilibrium

Chemical equilibrium covers several concepts, such as stoichiometry, limiting reagent, and chemical reactions, which are considered complex by specialists in didactics. Hence, illustrations that represented a chemical reaction were shown to the students, and questions regarding these concepts were presented to the sample. Moreover, a regular stoichiometry problem was included in the instrument, as well as a complete process of the answer (with the inclusion of some intentional mistakes). The students were requested to prepare a list of the concepts that were needed to solve the problem (instead of solving the problem), which they considered difficult for learning (a concept which demanded mastery of a large number of subordinate concepts [80]). This could be considered as a strategy for changing the idea about assessment as a result, because the main goal of the instrument was to ask the conditions for solving the problem. In this matter, it is relevant to mention that students prefer examinations which emphasize understanding and analysis, rather than tests of plain knowledge [81]. Nonetheless, despite awareness of the students' exam-type preferences, science teachers continue to administer their own conventional examinations. Indeed, it can be affirmed that students' success in algorithmic exam questions does not imply their success in conceptual questions, suggesting that success in solving algorithmic (conventional) test problems (paper-pencil problems) does not mean a conceptual understanding of chemistry [82].

A majority of students (21 out of 33) were able to use concepts related to stoichiometry and its subordinate concepts to solve the issue. Students that failed in this part had not acquired concepts such as element and compound. However, just 16 students out of 21 that appropriately identified concepts related to stoichiometry were able to establish the mathematical and quantitative relationships about limiting reagent. These difficulties showed that the mathematical operationalization of chemical concepts tended to be an additional factor that caused problems during the learning process. It was even more striking that five students were able to solve the mathematical situation, albeit that they did not list the basic concepts that allowed the resolution. It is common to use algorithms even if they are not understood [83].

To promote concept building and remediate any misconceptions, it is critical to provide students with opportunities to verbalize their ideas. Then it is possible for deep-seated misunderstandings to be identified, diagnosed, and addressed [16]. Thus, every student needed to perform a metacognitive process to identify his/her limitations. In the solved problem about stoichiometry, most of the students mentioned at least two concepts (stoichiometry by 17 students and equation balance by 12). Other less frequently mentioned concepts were mole, limiting reagent, excess reagent, and yield. Some studies have shown that the difficulties in solving problems depend on the capability of the learners, which generally focuses on surface features rather than developing an adequate conceptual understanding of the problem domain [84]. In this context, the task by itself forces the students to think about the process for solving the problem, and furthermore, to consider the limitations and strategies for overcoming these limitations.

Stoichiometry is considered as a complex concept and it is associated with misconceptions of chemistry language, no specific organization of thoughts in solving problems, the incorrect application of reasoning, and an unsupportive environment [85].

As a relevant point in this research, some difficulties related to chemical equilibrium originated in stoichiometry. For instance, students think that the concentrations of all the species involved in a chemical system are equal at chemical equilibrium, or even that concentrations of the reactants and

the products are identical at that moment. It might be attributed to the fact that students assume that equal stoichiometric coefficients should correspond to equal concentrations. Other difficulties occur when the molar ratio of reactants is different from 1:1, and very often students do not relate the reaction stoichiometry with the expression of the equilibrium constant [86]. However, the performed assessment in this research did not reveal any of the reported problems, and the concepts related to stoichiometry were geared into cognitive structures that might indicate an appropriate conceptual frame to approach the chemical equilibrium study.

As it was the first time that this kind of assessment instrument was presented to the students, they were asked about their opinion of it. Statements such as *it was not a real test* were given. Other comments such as *... having the solution to the problem handed to the student can be discouraging and pointless. Answers should be found by solving the problem* were mentioned. Another student indicated *... I feel terribly disappointed because I was doing well and then I got the answer and I know in which level I am working*. These arguments showed a tendency that was present throughout the investigation: few students considered that a solved problem was a learning strategy. Instead, synonyms as clarified concepts or review were reported. Students indicated that only instruments containing mathematical operations could be considered as “reals”, which was framed into the traditional chemistry assessment generally promoted by teachers.

The research showed that a majority of the sample thought that reagents were necessary if a chemical reaction was to be performed, although one third of the sample indicated that it was not possible to perform a reaction if there were not at least two reagents. This result indicated that students did not explain chemical reactions at a sub-microscopic level, but rather on the surface macroscopic features of reactants and products [87]. Therefore, it is plausible to infer that students might not have meaningfully integrated concepts, such as atom, molecule, element, and compound into the cognitive network. By virtue of this evidence, a specific strategy to differentiate the above-mentioned concepts was applied, although further details were not relevant within this document.

Concepts such as energy (heat and activation energy), collisions, and formation and breaking of chemical bonds were mentioned. These concepts could be categorized as difficult concepts for learning in the frame of chemical reactions. It is relevant to mention that 19 out of 33 students wrote at least one condition for a chemical reaction. One student said *... Some conditions are necessary if a chemical reaction takes place. It needs several collisions between reagents than therefore will form a product. This can be explained by activated complex and collisions theories. In summary, these theories establish that if a reaction takes place, effective collisions are mandatory between the particles of the reagents generally conditioned by the orientation of the molecules. On the other hand, the activated complex indicates that a minimum energy is required*. This student exhibited a well-developed chemical sense, which suggested the construction of the concepts, or in the context of this research, learning.

3.3. Didactic Strategy

Once the previous knowledge about basic concepts was identified, a work guideline was implemented in the frame of the Ignatian pedagogical paradigm. It included context, experience, reflection, action, and evaluation [64]. Two 90 min sessions were dedicated to work in the activities that included a literature review of textbooks, as well as a group discussion. Topics such as reaction rate, chemical equilibrium, Le Chatelier's principle, pH, acid and base theories, self-ionization of water, and buffer solutions were studied. In an extra session, an experimental work was carried out.

3.4. Relationship Between Reagents, Products, and Equilibrium Constant

In general, students considered that the numerical values of the right column were equal; therefore, it is worth mentioning that they could build conceptual relations using the expression of the equilibrium constant. As an example, one student affirmed *... I don't understand why it happens (values of the right column are equal or approximately equal), but I think equilibrium constant is not affected by the initial concentration of reagents*, which is a strong indication of learning during the assessment.

Nonetheless, seven students did not identify that changes in the concentration of the reagents did not affect the equilibrium constant, which might correspond to difficulty of predicting how an equilibrium system evolves if the system is altered. Students might predict this phenomenon using three different approaches: Le Chatelier's principle, the equilibrium law, and an analysis of reaction rates using collision theory [4], although the most frequently used is the former. It might be assumed that changing the concentration of one reagent shifts the equilibrium, but those seven students were unable to establish a relationship between the equilibrium constant and the expression of the equilibrium constant. Indeed, for these students, the reported misconception in which the concentrations of all species at equilibrium are equal appeared, and they considered that in chemical equilibrium conditions, the forward and reverse reaction rates are not equal [1] and that the concentration of reactant is equal to the concentration of products [24]. A question about the relationship between the initial concentration and equilibrium constant was presented to the sample. Although 24 students asserted that there was no correlation, six of them did not provide an argument for it from a chemical point of view. For instance, one student wrote *... by changing the initial concentration, the concentration at chemical equilibrium in all the experiments are similar and they just change a bit and in a non-uniform way. For that reason, the equilibrium constant does not change either*. In general, the sample identified that there was no dependence of initial concentrations and the equilibrium constant, which was in contraposition of the reported misconception that affirmed that at chemical equilibrium, the concentration of reactants was equal to the concentration of products [88]. These results might suggest that the assessment allowed the students to incorporate the concepts to their knowledge, and that the concept was meaningful to them. It was possible to affirm that an assessment could be considered as a learning tool.

Differences between equilibrium and reversible reactions were not established by the sample, and none of the students explained the difference between these processes. Three students indicated that they were not the same kind of reaction, although they failed to provide an argument that suggested an understanding of the two concepts, which was in concordance to the problem for interpreting the double arrow, one of the most common problems related to chemical equilibrium learning [18]. Four reasons might explain these misconceptions: (1) Students approach chemical equilibrium from their experiences with mechanical equilibrium; (2) traditional teaching uses physical analogies that may contribute to creating a static idea of the equilibria; (3) the concept of reversibility with the physical movement induced to achieve equilibrium when everything is equaled; and (4) the way to represent equilibrium with the double arrow separating the two sides of the equation may induce students to interpret the balance as two separate systems that evolve from one to another [86].

Numerous actions need to be considered for subjugating misconceptions, and the use of an appropriate language is essential. Within this framework, emphasis needs to be put on the differences between the direct and reverse rates, indicating that they are equal if the chemical equilibrium is reached, although neither amount of substance nor concentration for both reactants and products must be the same. Furthermore, indicating that the direct rate decreases whereas the equilibrium is reached might reduce the impact of the misconception related to equilibrium and reversible reactions [8]. Moreover, several publications describe how to identify misconceptions related to chemical equilibrium, although strategies to help overcome them are limited. Nonetheless, using an intentional strategy, the misconceptions might reduce its impact in the learning process [88,89].

At equilibrium, the rates of the forward and reverse reactions are equal, resulting in the dynamic "no overall change" position. However, it was established that the students considered forward and reverse reactions as separate events. These students may have directly confused the equality of rate and concentration. Moreover, students thought that changing conditions resulted in an increase in the rate of the favored reaction and a decrease in the rate of the other reaction. This finding was similar for undergraduate chemists and chemistry teachers. There was some evidence suggesting that students perceived the rates of one reaction in an equilibrium system might alter, whilst another slowed or remained constant. They had not grasped the notion that the rate applied to the system as a whole, rather than the component reactions. This difficulty is related to students' perception of two separate

reactions [90]. To help students, researchers have suggested a variety of instructional approaches, such as adapting teaching strategies based on the conceptual change model [23]. Thus, the questions 1, 2, and 3 create a cognitive conflict that favors a conceptual change. Within this frame, students could identify that the initial concentrations did not affect the equilibrium constant, and that concentrations of the species at equilibrium were not equal. By solving the situation, students were able to overcome the misconceptions. As the information was meaningfully integrated to previous knowledge, it could be mentioned that meaningful learning was achieved whilst the assessment was solved.

The problems related to Le Chatelier's principle can be addressed using assessment strategies that avoid its operationalization. For that reason, mathematical problems were not considered and questions towards analysis were proposed (Question 4). In them, the students were requested to analyze how the chemical equilibrium was affected instead of obtaining a numerical value, which sometimes did not indicate a significant meaning. Moreover, the question avoided the operationalization of Le Chatelier's principle, the use of the equilibrium constant, and it was not necessary to use the reaction quotient.

It is relevant to emphasize that the instrument allowed the students to build the difference between initial, final, and equilibrium concentrations.

3.5. Problem Situation about Chemical Equilibrium

A final test was presented to the sample (Appendix D) and most of them wrote precise but incomplete instructions. However, 16 students were able to obtain the equilibrium concentrations. Others proposed the expression of the equilibrium constant, although mathematical problems were mentioned as causes to not being able to finish the task. In fact, all the corrections had a chemical sense and solving the problem was possible with the instructions for 27 of the 33 students. Table 4 shows the frequency of instructions that students prepared.

Table 4. Actions that students take after getting their assessment.

Options	Frequency
Write the chemical equation	19
Balance the chemical equation	12
Determine the initial concentration	25
Determine the concentration variations	4
Determine the equilibrium concentrations	24
Write the expression of equilibrium constant	24
Replace the obtained values in the expression	19
Solve the equation	18

Several studies have identified common alternative conceptions held by students at the secondary and tertiary level, and these studies have made a number of recommendations for those engaged in teaching this difficult topic. A greater emphasis on the quantitative aspects of equilibrium may help students to gain a clearer picture of the relationship between the concentrations of reactants and products in equilibrium systems [4]. Within this frame, the instrument presents a synergy between assessment as a tool for learning, and a peculiar combination of factors, qualitative (list of instructions), metacognitive process (think about what can be done with the received information), and quantitative (solving the problem using mathematical algorithms). Thus, the reported misconceptions were overcome by the sample as evidenced by the number of students that were able to calculate with a chemical sense, the concentrations of the species in equilibrium.

It is important to underline that these kinds of instruments are characterized by the possibility of promoting higher cognitive competences. This quality is contrary to the traditional methods that often emphasize memorization. Furthermore, the relevance of feedback has been elucidated in scientific literature and it has been documented as one of the most powerful single influences in learning. Formative assessment emphasizes the extraordinarily large and consistent positive effects that feedback has on learning compared to other aspects of teaching [91].

3.6. New Ideas about Assessment

After pedagogical activities and assessment practices, the instrument related to previous ideas about assessment was re-presented to the sample. It was notable that twice the number of the students that expressed a negative perception at the beginning of the research exhibited positive attitudes (Table 2). For instance, one student indicated that *... now I know that I should not be guided by an answer, I should concern by learning and asking about concepts that I do not understand; instead of measuring me, I have been assessed by learning*. Participants that first indicated negative feelings were immersed into the paradigm of evaluation as a result. A meaningful change occurred regarding the actions that students took after receiving their test. Although grades were still a significant issue, four students ignored their grades and focused their attention on the answers, whereas in the first instrument, none of them contemplated that option and, even more relevantly, the common action to compare their answers experienced a paradigm shift: comparing answers became a tool to promote learning.

Students considered the assessment as a measurement activity, evidenced in the first part of this research where 20 students selected this option and just six subjects indicated that the main purpose of evaluation was to learn. However, after didactic intervention, assessment perception experienced relevant changes, and 14 and 10, respectively, have been censused in those categories. As can be noticed, a slight number of students had modified their opinion and they now thought that the assessment might be considered as a learning strategy, and the arguments were focused on the activities of metacognition. Furthermore, the collected information suggested that during the assessment, several conceptual changes were presented and then, it could be assumed that it was possible to learn concepts related to chemical equilibrium whilst the topic was being assessed. Simultaneously, the number of students that thought assessment was the responsibility of the teacher had reduced by up to 50%, whereas 60% of the sample mentioned after the strategy that the assessment process was shared between student and teacher. In fact, 30 out of 33 students identified that learning implied the development of new relationships amongst concepts. Consequently, they expressed processes such as revising, clarifying, and correcting. During the new assessment strategy, new concepts were developed. In other words, successful learning regarding chemical equilibrium was achieved during the assessment process.

4. Conclusions

Pedagogical debates are still focused on misconceptions as one of the most relevant difficulties that students and educators experience during the teaching–learning process. Abundant literature describes to a deeper extent how to identify misconceptions, its origin, and its intrinsic coherence. It is necessary, therefore, that the didactics of science propose a plausible solution. For that reason, the assessment as a primary element in the educational sciences needed to address the problem. As a strategy, assessment instruments related to chemical equilibrium were specifically designed to identify, in the first place, misconceptions, and as a tool for learning and overcoming these misconceptions. It was shown that students assessed using these instruments, built concepts regarding chemical equilibrium. Moreover, during the evaluation, students established differences between initial and equilibrium concentrations, and how the chemical equilibrium is affected by variations in the initial concentrations. Indeed, the operationalization of the Le Chatelier's principle was not systematically considered by the sample, and instead, a deep analysis of how the chemical equilibrium is re-established after a modification was taught and understood from the equilibrium law.

On the other hand, assessment implies a great variety of feelings and attitudes towards learning. It is evident that a vast majority of teachers is aware of this fact, but no relevant changes or adjustments are made to reduce its negative impact during the process. As established by the research, general assessment is framed into the transmission–reception model, and students consider it as a measurement instrument. Since evaluation is perceived as a crucial aspect, and in general, students exhibit very high levels of concentration while they are being assessed, it is important to use this moment as an outstanding opportunity for learning. Every assessment activity should consider that there is no other moment in which students are more available for learning than that. Thus, to assume that

assessment might facilitate learning of concepts related to chemical equilibrium is a gain. In addition, the experience of teachers indicates that there are concepts that are difficult to evaluate, and even more, they are generally evaluated in a traditional way. Nonetheless, this research shows that it is possible to identify misconceptions, approach them from a novel strategy, positively stimulate the learning of chemical equilibrium whilst the concepts are being assessed, and contribute to the development of the understanding of didactic of science, particularly in the field of chemical equilibrium, a concept that is considered as very complicated for learning.

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Appendix A

We would like to improve the assessment practices in chemistry courses. For that reason, we kindly ask you to answer the following questions. Select the option that best describes your experience during the assessment in chemistry classes.

1 Prior to an assessment in chemistry, you experience:

Security____

Tranquility____

Anguish____

Insecurity____

Please, justify your choice

2 As soon as your teacher returns your corrected assessment, you:

Ignore the grade and check out your answers____

Query the grade and review your answers____

Identify the questions where you had problems and rewrite them____

Compare your and your classmates' answers____

Other: _____ Which one? _____

Please, justify your choice

3 What do you think is the main reason for being assessed in chemistry courses?

For measuring your knowledge____

For repeating concepts ____

For approving the subject ____

For learning ____

Other: _____ Which one? _____

Please, justify your choice

4 Besides writing tests, oral test, laboratory reports, short exams, quizzes, and presentations, does your chemistry teacher assesses you through other techniques? Yes____ No____ Which one? Please, justify your choice

5 From the previous list, in which way would you like to be assessed in chemistry courses?

Please, justify your choice

6 Who do you think is the person that is responsible for chemistry assessment?

Teacher _____

Student _____

School _____

Both, teacher and student _____

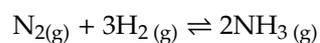
Other: _____ Which one? _____

Please, justify your choice

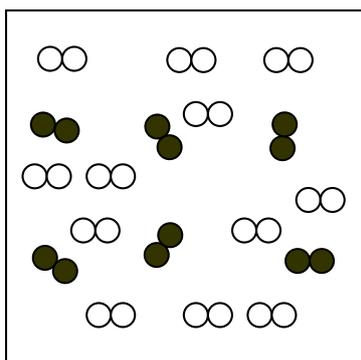
7 Do you consider that the assessment in chemistry courses allows you to learn? Why? Please, justify your choice

Appendix B

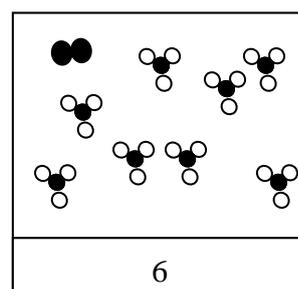
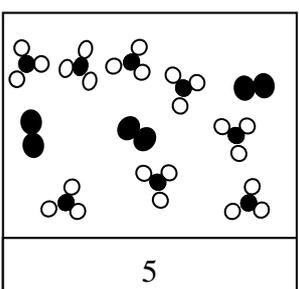
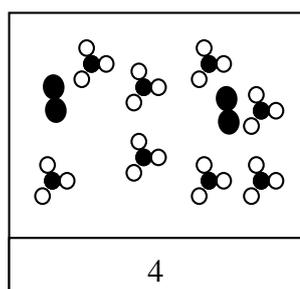
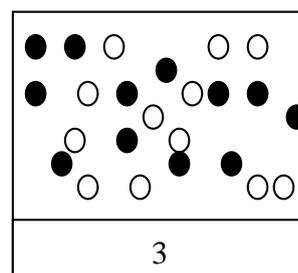
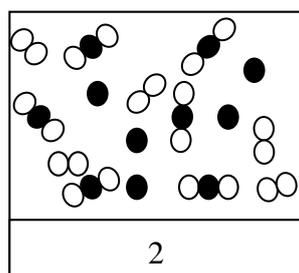
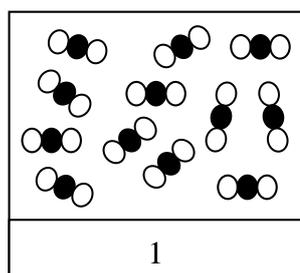
1 Ammonia can be produced by the direct reaction between nitrogen and hydrogen according to the next equation:



The next diagram denotes a small portion of the initial mixture. Black circles represent nitrogen atoms and white ones correspond to hydrogen ones.

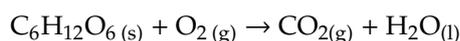


Which one of the following diagrams belongs to the product of the chemical reaction?



Which one of the following statements are true?

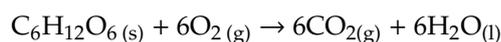
- Nitrogen is the limit reagent.
 - Hydrogen is the limit reagent.
 - Ammonia is the limit reagent.
 - There is no limit reagent. All the present substances are in a correct stoichiometric proportion.
- 2 A candy of one important company contains 21.1 g of glucose ($C_6H_{12}O_6$). After eating it, a metabolism reaction takes place according to the next equation.



- a. Balance the chemical equation.
- b. How much oxygen is consumed during the reaction?
- c. How many grams of carbon dioxide and water are produced during the metabolism?

Process of solving the problem

- a. Balance the equation by the inspection method.



- b. Use the molar mass for obtaining the amount of substance of glucose from grams

$$21.1 \text{ g GLU} \times \frac{1 \text{ mol GLU}}{180.2 \text{ g GLU}} = 0.1170 \text{ mol GLU}$$

Then, stoichiometric factors are used for obtaining grams of oxygen, carbon dioxide and water.

$$0.1170 \text{ mol GLU} \times \frac{6 \text{ mol } O_2}{1 \text{ mol GLU}} \times \frac{31.99 \text{ g } O_2}{1 \text{ mol } O_2} = 22.5 \text{ g } O_2$$

$$0.1170 \text{ mol GLU} \times \frac{6 \text{ mol } CO_2}{1 \text{ mol GLU}} \times \frac{44.01 \text{ g } CO_2}{1 \text{ mol } CO_2} = 30.9 \text{ g } CO_2$$

$$0.1170 \text{ mol GLU} \times \frac{6 \text{ mol } H_2O}{1 \text{ mol GLU}} \times \frac{18.02 \text{ g } H_2O}{1 \text{ mol } H_2O} = 12.7 \text{ g } H_2O$$

Water mass can be obtained using conservation of mass law.

Mass of reagents = Mass of products

Total mass of reagents = 21.1 g GLU + 22.5 g O_2 = 43.6 g

Total mass of products = CO_2 + g of H_2O = 43.5 g

Mas of water = 43.6 g – 30.9 = 12.7

These are reasonable answers because approximately 0.1 mol GLU requires 0.6 mol O_2 , and therefore, it produces 0.6 mol CO_2 and 0.6 mol H_2O . Therefore, any of the calculated masses should be higher than the correspondent molar mass.

- Describe the conditions for a chemical reaction can be carried out.
- Elaborate a list of all the concepts you need for solving the previous problem.
- From that list, which one you cannot understand and use for solving the problem?
- Would you affirm that reading and answering the questions it is possible to learn?

Appendix C

In the next table, some experimental data for a chemical equilibrium system at 25 °C are shown. $\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$. Gases concentrations are expressed in molarity and they can be obtained by calculating the amount of substances at the beginning, in equilibrium, and the volume of the flask in liters.

Initial Concentrations (M)		Concentrations at Chemical Equilibrium (M)		Concentration Ratios at Chemical Equilibrium
$[\text{N}_2\text{O}_4]$	$[\text{NO}_2]$	$[\text{N}_2\text{O}_4]$	$[\text{NO}_2]$	$[\text{NO}_2]^2/[\text{N}_2\text{O}_4]$
0.6700	0.0000	0.6430	0.0547	4.65×10^{-3}
0.4460	0.0500	0.4480	0.0457	4.66×10^{-3}
0.5000	0.0300	0.4910	0.0475	4.60×10^{-3}
0.6000	0.0400	0.5940	0.0523	4.60×10^{-3}
0.6000	0.2000	0.0898	0.0204	4.63×10^{-3}

Read and answer the following questions. Do not forget to justify.

1. Why do you think that the values of the column on the right are equal or approximately equals?
2. How is the equilibrium constant affected by the initial concentrations?
3. Do the equilibrium concentrations depend on initial concentrations?
4. If a small amount of N_2O_4 is added to the equilibrium system at a constant temperature and pressure, what will happen to the amount of substance of NO_2 when equilibrium is reached?
5. Is there a difference between a reversible reaction and an equilibrium reaction?
6. Indicate what concepts or relationship between them are hard for you understand. Explain your answer.
7. Why do you think you could or could not answer correctly the previous questions, and therefore, are hard for learning?

Appendix D

A mixture of 0.500 moles of H_2 and 0.500 moles of I_2 were placed in a 1 L container made of stainless steel at 430 °C. The equilibrium constant at that temperature was 54.3. How can the concentration at equilibrium be calculated?

1. Do not answer the problem. The task consists of writing a specific step by step protocol with the instructions for solving the problem.
2. Once the protocol is ready, give it to one of your classmates and ask him/her that following these instructions, they should try to solve the situation.
3. If the received list is uncompleted or it contains mistakes, fix it and give it back to the initial student. Analyze yours and your classmate comments and now try to solve the problem.
4. Do you think this kind of assessments might help you during your learning process?

Do you think that using this methodology, you were able to learn some concepts related to chemical equilibrium?

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