JOURNAL OF CHEMICAL EDUCATION

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Student-Generated Videos to Promote Understanding of Chemical Reactions

Published as part of the Journal of Chemical Education virtual special issue "Teaching Changes and Insights Gained in the Time after COVID-19".

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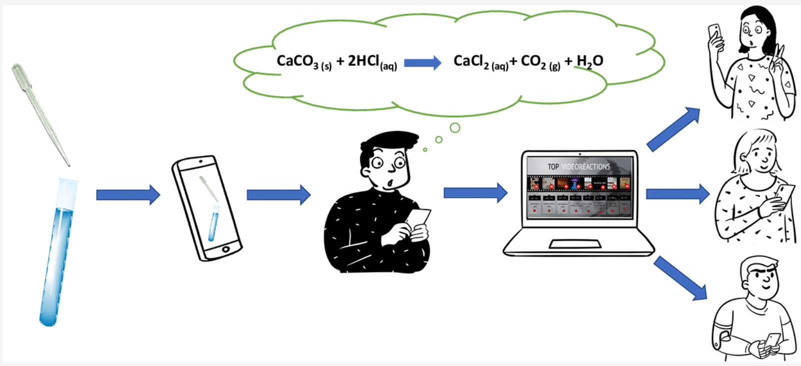
Cite This: J. Chem. Educ. 2023, 100, 1039−1046 Read Online



ABSTRACT: Students were tasked with the creation of videos of ordinary reactions to promote significant learning of complex concepts underlying chemical transformations. Interactive infographics were used to deliver instructions. Afterward, students planned the experimental setup for the reaction execution and video recording using their mobile phones. The videos and an online questionnaire, also created by the students, were shared with other class members using the visual platform Padlet. The reasoning required to elaborate the questions contributed to a better understanding of the principles underpinning the chemical equation. An exit survey showed that planning and performing the activity were not time-consuming for the students. Marks attained by the students in questions related to chemical reactions improved after completing the activity.

KEYWORDS: *First-year Undergraduate/General, Second-Year Undergraduate, Inorganic Chemistry, Laboratory Instruction, Multimedia-Based Learning, Collaborative/Cooperative Learning, Reactions*

■ INTRODUCTION

Reductionism is "the idea that complex systems or phenomena can be understood by the analysis of their simpler components".[1−3] This approach, which dominated science and chemistry education for many years with notable successes, also has obvious limitations; for example, the fact that when focusing on the individual elements of complex phenomena, students fail to grasp the often essential interconnections that lead to a true understanding. Opposed (or rather complementary) to this concept, holistic models aim at the interconnections and synergies between the different components of a complex system to fully understand its nature. One holistic modern approach is "system thinking" which intends to give students an overall view of real-world problems of intricate nature and multidisciplinary characteristics that they, as future citizens and scientists, will face.[2−5]

Also, a holistic view with a long tradition in chemistry is Johnstone's model[6−8] which proposes that chemistry education and learning operate at three different levels because of its complex nature. These levels, often labeled as the macroscopic, the submicroscopic, and the symbolic, represent the tangible observations: the molecular or particulate level (atoms, molecules, ions, structures, etc.) and the different symbolic representations of chemical phenomena (Johnstone gave as an example the formula equation representing sodium chloride dissolving). This concept is frequently represented with a triangle (Johnstone's triangle) with the three apexes labeled with the macroscopic, submicroscopic, and symbolic terms. The model is also known as the chemistry triplet and has been widely

Received: August 19, 2022
Revised: January 17, 2023
Published: February 3, 2023

used as the conceptual foundation for countless investigations in the field of chemical education.[8−24] The holistic Johnstone's model shows its utility as a framework that allows students to establish relationships between the different components of its triangle. This continuous switch between the three levels is a sort of "mental gymnastics" which gives the student an overall view of the complex nature of chemistry.

Chemical transformations are one such complex system that may be studied in their different levels: the submicroscopic level represents reaction mechanisms, thermodynamic transformations, kinetic considerations, or bonding implications. The reactants and products resulting from the chemical change are represented symbolically using chemical equations. The third level, the macroscopic, implies the observation of changes in the reaction mixture during the chemical transformation.

On the other hand, the use of videos as a tool to enhance learning has a long tradition in chemistry. Particularly, and due to the needs created by the COVID-19 pandemic confinement, this teaching strategy has experienced exponential growth, as shown by the numerous articles published in the special issue[25] of this journal dedicated to teaching during the pandemic. In a wide approach, we may classify videos as those generated by instructors, thus designed to be watched, more or less actively, by students and student-generated videos in which the student must adopt the active attitude desirable to promote significant learning. The application of this teaching tool in chemistry education is less frequently reported in the literature. Examples included its use to improve understanding of molecular models,[26,27] interactions at the molecular level according to Johnstone's model,[28] or organic reaction mechanisms.[29] This didactic strategy has also been used in laboratory-related activities,[30−32] to promote awareness of green chemistry, or as an assessment tool.[33−36] In some examples, the videos created by the students were posted on video-based social media platforms with wider educational aims.[337−39] The use of this teaching tool in chemistry education has been reviewed by Gallardo-Williams et al.,[40] who classified student-generated videos according to three general categories: (i) asking students to prepare a video about a technique in preparation for laboratory work, (ii) asking students to prepare a video in the laboratory to demonstrate general chemical understanding incorporating some practical activity, and (iii) asking students to demonstrate competence in a laboratory experimental technique. In any case, this teaching approach may be considered in the general framework of generative learning theory according to which the creation of knowledge requires active construction so that learners take actions to produce new knowledge and establish relationships with the already known information to enrich learning.[41,42]

The authors also framed student-generated videos in the conceptual model of Johnstone: "This consideration is of primary importance in chemistry, a subject that relies on consideration of multiple representations as described in the manifestation of representations by Johnstone's triangle (macroscopic, microscopic, symbolic) and also because of the physical nature of the chemistry laboratory".[40]

Gallardo-Williams gave four arguments to justify the inclusion of student-generated videos in the chemistry curriculum.[41]

(1) that the approach is grounded in a framework of generative learning theory, enabling students to use tangible imagery and narratives to elicit their explanations and/or understandings
(2) that the approach helps develop transferable skills including digital literacy
(3) that it allows for multimodal pedagogies and assessment and the consequent advantages to curriculum accessibility
(4) that it improves students' emotional interaction with teaching and learning activities, and thus within the framework of meaningful learning, is beneficial

The COVID-19 pandemic has also expanded experiences of remote collaborative work for which a wide variety of tools are available. Among these, Microsoft Forms[43] is an intuitive application designed to create and share interactive questionnaires by groups of students; this application also implements simple methods of assessment and feedback. Padlet is a sort of virtual notice board to share resources from different media such as video and images in a very visual and attractive environment.[44−47]

Additionally, video recording and sharing are part of the student's social and educative daily life, as shown by the fact that the use of social media platforms with video-sharing facilities is widespread among young people. For example, in 2019, YouTube was used by 73% of Spaniards between 16 and 30 years old and Instagram by more than 65% of people in the same age group.[48] Furthermore, students use video-sharing platforms such as YouTube, not only for recreational purposes but also to gather information and the formation of chemical topics.[33,49]

On the other hand, we found that our students have problems answering questions aimed to complete chemical equations by giving the resulting products. In many cases, they try to memorize all the possible results instead of making an effort to understand the chemical basis necessary.

This is, probably, due to the difficulty of interconnecting the symbolic and submicroscopic levels. Ideally, the student must first determine if the reactants are pure substances or solutions and categorize them according to one of the bonding models and, finally, choose the appropriate type of reaction, among the countless studied at different times and in different contexts. This means accessing the long-term memory to retrieve pieces of information apparently disconnected, choosing the adequate ones, and putting them together to solve the question. In other words, using the already known information to create new knowledge according to the generative learning theory.

For example, the two equations

$$NaCl + H_2O \rightarrow$$

$$SnCl_4 + H_2O \rightarrow$$

are apparently similar since both represent the behavior of halides in water. To deal with this problem the student must first determine the type of bonding, which means positioning the metal atoms and the halide in the periodic table. Next, the student must identify the chemistry of sodium as cationic and chloride as anionic and decide if this particular salt is soluble in water. Finally, he or she must assess the acid−base characteristics of the cation in solution as a function of their density of charge and electronegativity. All this complex mental processes will conclude that NaCl dissolves to give $NaCl_{(aq)}$ or $Na^+{}_{(aq)}$ + $Cl^-{}_{(aq)}$, ideally knowing the meaning of the (aq) symbol. Obviously, students may also skip all the reasoning by simply remembering that NaCl is table salt. This, one of the simplest examples of a chemical equation, known by our students since the first years of secondary education, gives in many cases NaOH + HCl, according to them.

https://doi.org/10.1021/acs.jchemed.2c00813
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The behavior of $SnCl_4$ in water is, apparently, much more complex. First, identifying the halide as a molecular solid requires using, for example, Fajan's rules to predict the covalent character according to the charge/radius ratio and electronegativity of tin. Then choose between two models to predict reactivity in water: the acid−base behavior of an imaginary Sn(IV) cation that will behave as an acid (a Pourbaix diagram is useful to rationalize the behavior of metal ions in solution) or, alternatively, the thermodynamically favorable formation of SnO_2 and to the presence of empty low-energy orbitals in tin to predict the hydrolysis reaction. This, seemingly much more complex reaction is correctly answered by students that failed the apparently simpler NaCl dissolving in water, showing the difficulty of retrieving the known information (NaCl = table salt) and connecting it with the new model (acid−base behavior of metal cation) to generate the new knowledge and give the correct output.

Adding the third corner of Johnstone's triangle, the macroscopic level, will reinforce the learning process as the students associate the observed changes during the reaction with the properties of the species reacting and being formed.

Additionally, the experience gained during the COVID-19 pandemic gave us and the students the skill necessary to use a range of new tools that could be of great utility in dealing with this complex situation. In this context, we reasoned, that adding the creation of videos will contribute to reinforcing the relationship between the three levels in several forms.

First, the constructivist character of this teaching tool seemed to promote an active attitude among the students, compared, for example, to an ordinary written report. Second, because videos will be seen by all the students in the group, consequently, the creators should put themselves in their classmate's place. This means that the student adopts the role of a teacher, which requires a level of reflection over all of Johnstone's levels difficult to achieve with less active didactic tools. Additionally, the ludic character of recording videos was expected to increase the emotional engagement and attitude toward the subject which will facilitate meaningful learning.

Bearing this in mind we designed an activity in which students created videos of simple chemical reactions that they performed working in small groups. The collaborative character of the activity was reinforced by promoting remote teamwork since the students elaborated on questions about the recorded reactions and posted them together with the videos they had created. These questions should be answered by their class fellows to gauge their understanding of the chemistry underpinning the video. We expected that the reflection necessary to understand the chemical models used to predict the reaction product and to question other students would improve the "mental gymnastics" necessary to achieve meaningful learning. Students were allowed great autonomy in the design and execution of the activity.

Context and Objectives

This activity was designed for Inorganic Chemistry Two, a second-year subject in the Chemistry degree at the University of a Coruña, a public university located in the northwest corner of Spain.

Inorganic chemistry two is dedicated to the study of metal elements and their compounds including their structure, preparation, reactivity, and applications. To describe and rationalize the chemistry of metals and their derived ions in aqueous solutions, we use, among other tools, Pourbaix diagrams that allow a visual description of their behavior as a function of pH and potential. However, proper understanding and use of such diagrams are difficult due to the number of variables implied.

Inorganic Chemistry two has also an experimental part that is mainly dedicated to the preparation of metals, and their compounds (including metal complexes). There was a total of 20 laboratory hours in which the students synthesized an average of three substances. There are periods scattered through the lab hours that do not require continuous attention. For example, slow reactions, reflux heating, solid-state muffle furnace synthesis, drying periods, or recrystallizations, etc. On average, we estimate that 20−25% of the total laboratory time was idle periods, which ordinarily we dedicated to short experiments demonstrating a chemical principle of interest.

We decided to dedicate these idle periods to improving the student's understanding of chemical reactions. With this purpose in mind, we devised an activity called "videoreactions". We reasoned that designing the laboratory procedure for the reaction, recording, and editing videos of the laboratory experiment should help connect the three different levels of chemical systems: macroscopic, submicroscopic, and symbolic, promoting meaningful learning.

The overall objective of this activity was to promote a deeper understanding of chemical transformations among our students. To achieve this goal, we encouraged continuous change between the three levels given by Johnson's triangle. So, we posed our students with a chemical equation that had to be completed at the symbolic level and then carried out and recorded at the macroscopic level in the laboratory. To solve the equation the students had to first determine the nature of the reactants (structure and bond) and then choose the adequate model that gave the right output.

The use of student-generated videos was expected to improve the result in different ways: first students had to plan ahead for the recording, so they should anticipate a particular macroscopic result from the reaction, which meant connecting the symbolic and macroscopic levels. Let us bear in mind that the videos were going to be watched by the student's classmates, thus they had to plan the recording to clearly highlight the relevant macroscopic changes during the reaction; second, the active nature of this teaching tool was expected to promote meaningful learning; third, the ludic nature of video recording was expected to improve the attitude of students toward learning and to increase engagement.

The recorded videos were shared online with classmates, along with two questions the students that create each video had to pose to be answered by colleagues with the intention of gauging if they understood the principles underlying the macroscopic level recorded. By forcing our students to create such questions we aimed further reflection on the chemical principles underpinning the macroscopic and symbolic levels. Teamwork and online collaborative work also reinforced reflection and active learning.

Consequently, we proposed to the group of students several chemical reactions (Table 1). We divided the reactions into two groups. The first group comprised reactions of oxides and halides which were classified according to the nature of bonding. The second group of reactions involved metals with different activity according to their redox potentials, starting with sodium and ending with the less reactive copper. Such reactivity could be explained according to the normal potentials but also the use of Pourbaix diagrams in which potentials were intrinsically

Table 1. Reactions and Target Concepts

Equation	Target Concepts
$CaO(s) + H_2O(l)$	Bonding: ionic, solid; chemical behavior: basic
$CaCO_3(s) + HCl(dil)$	Bonding (CO_2): covalent, gas; chemical behavior: acid, carbonate conjugated base
$NaCl(s) + H_2O(l)$	Bonding: ionic, solid, Na^+ not polarizing cation; chemical behavior: not acidic cation
$SnCl_4(l) + H_2O(l)$	Bonding: covalent, liquid; chemical behavior: Lewis acid, hydrolysis
$Zn(s) + HCl(aq)$	Chemical behavior: Pourbaix diagram, reducing metal vs weak oxidant
$Na(s) + H_2O(l)$	Bonding: metal bonding, soft metal; chemical behavior: strongly reducing agent
$Cu(s) + HCl(dil)$	Chemical behavior: Pourbaix diagram, stable in water, weak reducing agent
$Cu(s) + HNO_3(conc)$	Chemical behavior: weak reducing agent vs strong oxidizing agent

contained. Each reaction was chosen to exemplify one type of reaction studied in class.

Then, students should record a video of each of such reactions as described below. The activity was carried out in groups of about ten students which were subdivided into subgroups of two or three students; the recording of two of such reactions was assigned to each subgroup. The activity was designed to be performed during the normal practical laboratory classes using downtimes during ordinary experiments. Therefore, they should be conducted in brief periods of time and, overall, not excessively time-consuming.

DESCRIPTION

The activity should be relatively brief, but, having several steps (Figure 1), it might be somewhat confusing, and instructions are necessary. Furthermore, several platforms were used during the different stages of the activity: Moodle as the starting point; Padlet, to post the recorded videos; and Microsoft Forms implemented in the Microsoft 365 environment, to post and answer questions and take the final survey. We have found that in this complex environment, the traditional methods to deliver instructions were not satisfactory. For example, the above-mentioned platforms were accessed through interactive links that could not be given orally or in a noninteractive written form. In our experience, the difficulty to transmit instructions related to multiple online sources caused confusion to the students and an endless number of questions related to the procedure itself rather than to the objectives and the chemical background. Consequently, the written instructions and links to the different activities should ideally be gathered on a site only as interactive and friendly as possible.

Therefore, with this purpose, we chose an infographic elaborated with the intuitive tool Genially[50] (Figure 2) and presented it to the students through the e-learning platform Moodle. Genially had previously been used to create a digital Escape Room[51] but not, to the best of our knowledge, to deliver instructions. Genially was freely accessible, easy to use, visually appealing, and supported text, audio, and video formats. In our opinion, this way of delivering instructions was also closer to the common experience of our students who are immersed in a partly analogical, partly digital world of mobile phones, apps, and social media.

This was similar to the other applications used in the activity. Microsoft Forms and Padlet were intuitive and did not require previous training or reading instructions. We must bear in mind that the main objective of this activity was to promote significant learning, not to increase digital skills. Anyway, the improvement

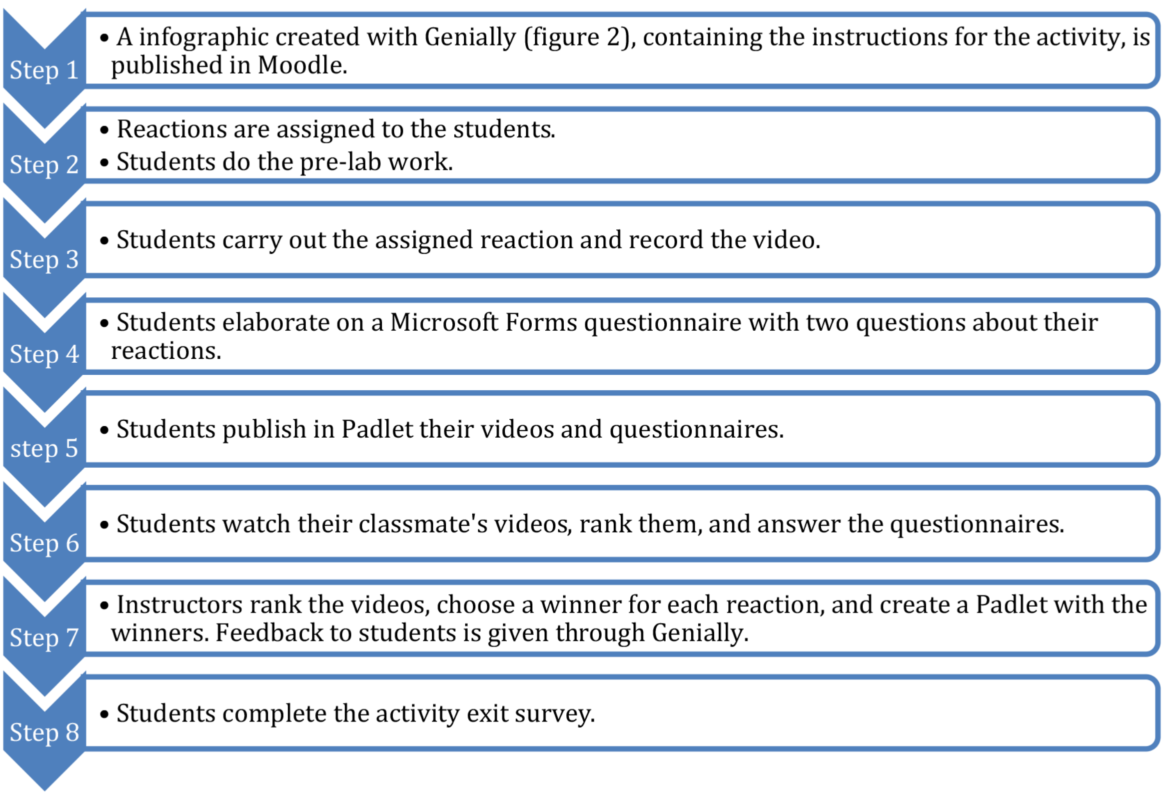

Figure 1. Flowchart showing the activity steps.

https://doi.org/10.1021/acs.jchemed.2c00813
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Figure 2. Genially generated infographics showing the instructions for the activity.

Figure 3. Genially generated infographics showing selected "videoreactions" and instructor's comments.

in such abilities experimented on by our students due to the COVID-19 pandemic facilitated the development of the mentioned activity.

Author: After assigning reactions to each group, students had to complete and balance (in general students had no problems balancing the equations) the corresponding chemical equation; to achieve this aim the students had to identify the reactants according to covalent, ionic, or metallic characteristics and then chose the model that justified the reactivity according to the chemistry already known from the course content (connecting the symbolic and submicroscopic levels). Once the products were known, it was necessary to choose the experimental conditions (see the Supporting Information). For example, the students should decide if it was adequate to use concentrated hydrochloric acid for its reaction with zinc or, if a change in pH was expected, how to visualize this change. This meant connecting the submicroscopic and the macroscopic levels. At this stage, safety considerations were necessary to decide the experimental conditions. This planning should also consider that the recorded videos would be watched by all the students in

https://doi.org/10.1021/acs.jchemed.2c00813
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the group, so the macroscopic changes in the reaction had to be clearly shown in the light of the models used; for example, changes in pH, gases appearing, substances dissolving, etc. This added additional reflection as students had to put themselves in the position of the viewer. Once checked with the instructor, the student carried out the reaction, recording the experiment with their mobile phones. All experiments were straightforward and could be carried out in no more than 10−15 min and might be conducted by the students themselves, except for the reaction of sodium and water, for safety reasons. Once recorded, video editing could be necessary; in any case, a very simple process should be used. One of the conditions sought was the shortness, as the reactions should be carried out during idle periods of time among ordinary experiments. After editing, the students published the video in Padlet under a header containing the corresponding chemical equation. Beneath the video icon, a link led to a Microsoft Forms document, elaborated by the group of students to which the reaction was assigned. The forms should contain two questions that the remaining students had to answer after visualizing the corresponding video. So, the authors of the video should reflect on the chemistry underpinning the reaction and propose the two questions to gauge the degree of understanding of their classmates. We expected that such reflections triggered significant learning. The videos could also be rated by classmates. Finally, instructors reviewed all the recorded "videoreactions", chose one video for each reaction, and created a new Genially post (Figure 3). Under each of the selected videos, instructors added a commentary, showing the complete equation as well as the chemical concepts used to solve the equation, summarizing the principal mistakes made by the students when answering the questions posted by their classmates.

■ RESULTS

The activity was assessed by different means. First, an exit survey (Table 2, Table 3) showed that the different stages that comprised the activity took them a reasonable amount of work. The activity was intended to occupy breaks during ordinary laboratory practices; consequently, we were concerned by the time dedicated by the students to prepare and conduct the experiments video recording and editing, etc. According to the survey, they dedicated, on average, less than one hour to the different steps of this activity.

Table 2. Students Exit Survey, Technical Questions[a]

Survey Questions	Average (std dev)
Rate the level of difficulty of editing the video.	2.3 (1.0)
Rate the level of difficulty of creating the Microsoft Forms questionnaire.	1.9 (1.2)
Rate the level of difficulty of using Padlet.	1.4 (0.6)

[a]38 responded (scale between 1, easy, and 5, difficult).

Table 3. Students Exit Survey, Learning Questions[a]

Survey Questions	Average (std dev)
Do you think that doing the reaction and recording it on video has helped you learn?	4.3 (0.8)
Do you think that thinking about and writing the quiz questions about the video has helped you learn?	4.2 (1.0)
Do you think that watching your classmates' videos and answering their quizzes has helped you learn?	4.0 (1.1)
In general, do you think that the activity has helped you to better understand the reactions that we study in the theoretical part of the subject?	4.3 (0.9)

[a]38 responded (scale between 1, disagree, and 5, agree).

Students found the use of Microsoft Forms and Padlet easy and video editing moderately difficult. In general, they had little difficulty using the technical tools required.

On the other hand (Table 3), most of them thought that the activity contributed positively to understanding chemical reactions. In fact, all 38 opined that the activity should be repeated in the following courses.

Second, one of the questions (reactions question) in the final exam the students took contained several chemical equations they had to complete by giving the final products. The reactions were chosen to represent the most important types of those studied during the course. We reasoned that to complete such equations, students should be able to adequately combine the different models and theories described above. Therefore, the marks attained in such question would be a good indicator of the accomplishment of the intended objectives.

An additional advantage of this assessment method was that a similar question (same number and kind of reactions) has appeared in the final exams since the academic year 2019−2020, allowing us to compare the marks attained during a reasonable period.

As can be seen in the related graphic (Figure 4) average marks corresponding to the reactions question experienced a statistically significant (Table 4) improvement compared to previous years.

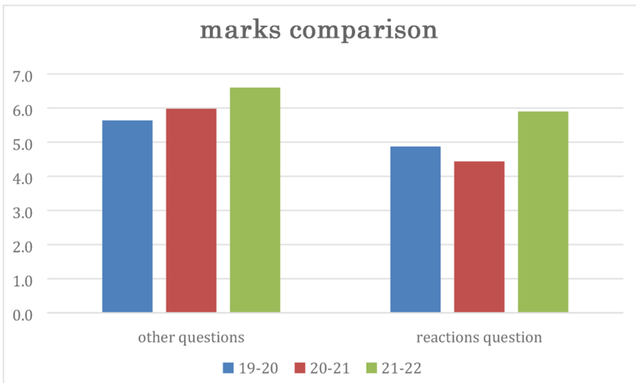

Figure 4. Average marks (0 to 10 points) attained by our students in the question directly related to chemical reactions (reactions question) and the remaining questions in the final exam.

A deep understanding of chemical transformations would, reasonably, favor the meaningful learning of many concepts

Table 4. Statistical Information for Comparing Mean Marks[a]

	Academic Period	N	Mean Mark	Adjusted p Value
Remaining questions	2019/2021	121	5.4	5.0×10^{-3}
Remaining questions	2021/2022	38	6.6	
Reactions question	2019/2021	121	4.3	4.8×10^{-5}
Reactions question	2021/2022	38	5.9	

[a]Two-tailed unpaired t tests were used to compare means with α = 0.05.

https://doi.org/10.1021/acs.jchemed.2c00813
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studied during the course, and therefore, an increase in the marks attained by our students in other questions of the exam was expected. As can be seen in Figure 4, the average mark for those remaining questions grew from *ca.* 6 (maximum 10 points) in previous years to 6.6 points, indicating an improvement (see Table 4).

However, other factors could also explain such an increase. For example, the consequence of the COVID-19 pandemic that strongly affected teaching during the previous 2019–2020 and 2020–2021 academic years had an influence difficult to extricate. To cope with this effect, we decided to compare the marks attained in the reactions question with the marks students got in the remaining questions of the exam.

Figure 5 shows that the comparison rate (90% in the 2021–2022 academic year) also improved, compared to previous years

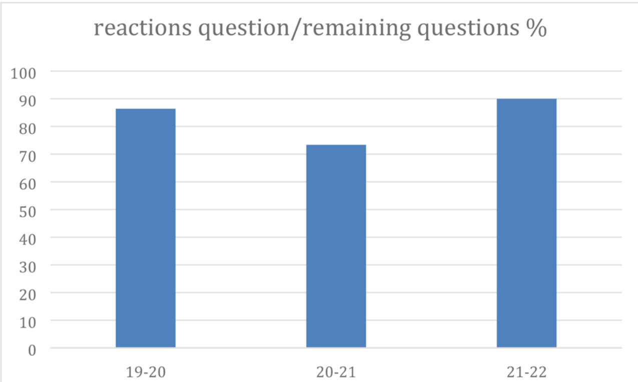

Figure 5. Ratio: average mark in the reactions question/average mark for the remaining questions × 100. 100% means that both average marks are equal.

but not so clearly. Therefore, the increase in the reactions question (in which the activity herein described had, logically, a large influence) in 2021–2022 compared to previous years was larger than the increase in the remaining questions (in which a lesser influence on the activity was expected), indicating that overall, the video reactions had a positive effect on the course results.

CONCLUSIONS

In the activity herein described, we applied didactic strategies rehearsed during the COVID-19 pandemic to deal with an old problem, the poor understanding of the concept of chemical reactions. With this purpose in mind, we devised an activity combining videos generated by the students with collaborative work using Padlet and Microsoft Forms. We also used Genially to provide friendly instructions given the multistep nature of the activity. Large autonomy was given to the students to design and execute the task. Analyses of students' marks indicated a moderate increase in the exam results directly involving chemical reactivity.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available at https://pubs.acs.org/doi/10.1021/acs.jchemed.2c00813.

Detailed instructions for students, exit survey, and examples of lab protocols including safety considerations (PDF, DOCX)

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Notes

The authors declare no competing financial interest.

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https://doi.org/10.1021/acs.jchemed.2c00813
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