Educación Química

COVID-19 school disruptions as drivers of curriculum change in the forensic science organic chemistry laboratory

Interrupciones escolares ocasionadas por el COVID-19 como impulsores del cambio curricular en el laboratorio de química orgánica de ciencia forense

Luis Jiro Suzuri Hernández,[1] Laura Alicia Espinosa Escobar,[1] Ana María Sosa Reyes, [1] Jorge Luis López Zepeda[1] y Luis Alexa Villavicencio Queijeiro[1]

Recepción: 2020-09-04
Aceptación: 2020-11-16

Resumen

El COVID-19 trastocó severamente el tipo de enseñanza que los estudiantes de todos los niveles educativos —en todo el mundo— recibían, impactando en especial a aquellos cursos cuyos resultados de aprendizaje incluyen el desarrollo de habilidades prácticas que dependen del trabajo en el laboratorio. Aunque la migración a la educación a distancia ocurrió de manera abrupta e inesperada, significó una oportunidad para los profesores de la Licenciatura en Ciencia Forense de la UNAM para reflexionar sobre sus métodos de enseñanza, en particular, de los que se aplican en el laboratorio de Química Orgánica, así como sobre el papel que estos desempeñan en el cumplimiento de los objetivos de la asignatura. El análisis incluyó la evaluación de las actividades prácticas previas a la pandemia, aplicando los criterios de tres diferentes instrumentos desarrollados para este tipo de actividades. Los resultados indican que en general, las tareas realizadas en este laboratorio favorecen la comprensión conceptual y la adquisición de competencia técnica en el uso de materiales e instrumentos. Sin embargo, parece ser que estos aprendizajes dejan poco tiempo para la reflexión sobre aspectos de la naturaleza de la ciencia torales para la formación de los científicos forenses.

Palabras clave

Primer año de pregrado / general, plan de estudios, instrucción de laboratorio, aprendizaje a distancia / autoinstrucción, química forense

Abstract

COVID-19 severely disrupted the way students, worldwide, are taught. Courses that rely on hands-on activities to achieve their educational goals have been particularly affected because not all practical skills can be taught effectively outside specialized spaces like laboratories. In spite of the unplanned shift to distance learning, instructors at UNAM's Forensic Science Undergraduate Program seized this opportunity to engage in a careful examination of teaching practices in the Organic Chemistry laboratory and the role these practices play in realizing the goals of the curriculum. To assess laboratory teaching, we analyzed the laboratory activities completed before shutdown against the criteria of three assessment instruments. Overall, the tasks carried out in the laboratory appear to favor the development of conceptual understanding and the acquisition of technical proficiency in the use of materials and instruments. However, it seems that these aims overshadow other important ones and leave little time for reflection on aspects of the nature of science that could strengthen the research background of forensic scientists. Determining how to adapt laboratory teaching to distance learning must be preceded by a thorough appraisal, not only of the technical obstacles, but also of the aims of the curriculum—particularly when teaching chemistry to non-chemists.

Keywords

First-year undergraduate/general, curriculum, laboratory instruction, distance learning/self-instruction, forensic chemistry.

[1] Licenciatura en Ciencia Forense, Facultad de Medicina. Universidad Nacional Autónoma de México

Cómo citar: Suzuri Hernández, Luis Jiro, Espinosa Escobar, Laura Alicia, Sosa Reyes, Ana María, López Zepeda, Jorge Luis , Villavicencio Queijeiro, Alexa. (2020, diciembre). Covid-19 school disruptions as drivers of curriculum change in the forensic science organic chemistry laboratory. *Educación Química, número especial*. DOI: http://dx.doi.org/10.22201/fq.18708404e.2020.5.76857

Educación Química

Introduction

Chemistry is a crucial tool for many forensic investigations, since the analysis of physical evidence from a crime scene often involves identifying unobservable substances or materials, separating them from support matrices and/or contaminants, and measuring their amounts. Pills, powders, plant matter, blood, urine, tissue, hair, fire debris and accelerants, gunshot residues, bullet lead, propellants and explosive mixtures, pre- and post-blast samples and residues, soil, glass, paints and inks, fibers, plastics, and paper are the most common objects, substances and materials submitted for chemical analysis in the course of everyday forensic casework (Bell, 2009). Reliance on chemical expertise to answer questions related to the administration of justice can be traced back to the first half of the 19th century, when the Spanish chemist and toxicology pioneer M. J. B. Orfila (1787-1853) testified for the prosecution in the trial of Marie LaFarge, having discovered arsenic in her husband's exhumed body (Bell, 2014, p. 9). The application of chemistry to poisoning cases ranks as one of the first applications of modern science to judicial matters. Today, like never before, forensic science has become an interdisciplinary endeavor that brings together a wide range of disciplines—from the physical to the social sciences—to assist in establishing the facts of a case. In spite of this diversity of expertise, which speaks to the complexity of forensic problems, chemistry remains one of the cornerstones of forensic teaching and practice: in a review of 78 forensic science courses offered worldwide by higher education institutions, Samarji found that almost 23 per cent of them—the highest proportion of all—were administered by Chemistry Departments, surpassing the number of offerings from other departments, such as those of Biology and Criminal Justice (Samarji, 2012).

In 2013, in response to Mexico's decades-long crisis of its criminal justice system—besieged by drug trafficking organizations and facing mounting complaints of military and police abuse and torture, enforced disappearances, and extrajudicial killings (Lee, Renwick and Cara Labrador, 2020) —the National Autonomous University of Mexico (UNAM) created the country's first undergraduate program in Forensic Science. Its chief aim is to train forensic scientists capable of aiding both the police in the investigation of allegedly criminal acts and in the processing of crime scenes, and prosecutors or defense attorneys in case preparation (Facultad de Medicina, 2013, pp. 2-7, 19, 37-45). To this end, the curriculum includes subjects from eight core disciplinary areas: physics, chemistry, biology, medicine, psychology, criminalistics, research methods, and the law, with a strong emphasis on the development of research skills (Forensic Science Undergraduate Programme in a Nutshell, 2015). Students in the program are not meant to train to perform chemistry laboratory work, as an aspiring analytical chemist would be. From the earliest stages of the program's creation, UNAM's School of Chemistry—fully aware of the importance of the discipline for forensic investigations—actively participated in the design of the curriculum, which in its actual form comprises three foundational courses—General Chemistry, Organic Chemistry (OC), and Biochemistry—and three specialized ones—Forensic Chemistry, Toxicology, and Hematology and Serology. All courses require students to perform a sizeable amount of hands-on laboratory work. Not surprisingly, given that forensic scientists are a recent addition to Mexico's higher education landscape, the curricula of the foundational courses share significant similarities to those of the same courses taught in the School of Chemistry— its design most certainly influenced by the knowledge and skills chemistry teachers believe will prepare professional chemists to meet the demands of the workplace.

Even before COVID-19 began spreading, forcing the closure of universities and the shift to distance learning, the chemistry instructors in the Forensic Science Undergraduate Program (FSUP) were engaged in discussions about how to better align their curriculum

DOI: http://dx.doi.org/10.22201/fq.18708404e.2020.5.76857

with the professional skill set expected of forensic scientists in Mexico, which is not the same of that of forensic chemists. Apart from the challenge of teaching chemistry for non-chemists, limited teaching time is one of the main obstacles faced by instructors: students enrolled in the program receive only one-fourth of the instruction in OC that a peer would receive in the School of Chemistry (i.e., only one semester versus four). Compounding the issue, as is the case in most public education institutions in Mexico, resources tend to be scarce, making laboratories a significant financial investment for higher education institutions—a concern that has been highlighted recently, and with renewed interest, due to the pandemic (Bretz, 2019; Arnaud, 2020). In summary, there is a pressing need to target chemical education to the specific training needs of forensic scientists while making more efficient use of the time and resources available for laboratory instruction.

By mid-March, unable to continue as planned, the half-completed OC course in the FSUP had to be abruptly redesigned for online learning. Laboratory sessions were cancelled and replaced by tasks such as readings followed by quizzes, synchronous videoconferences, and problem sets with IR/NMR spectra. Assigning at-home laboratory activities was considered at one point, but the short timeframe of the shift to distance learning meant that many students would be unprepared—in terms of materials and equipment—to carry out laboratory experiences in their homes, and neither could they freely go out to purchase them without risking their health. Likewise, the two OC instructors were wary of asking students to incur any additional expenses at a time of economic uncertainty. In this context, instructors began thinking not only of how to successfully conclude the term, but also what changes could be implemented in the future to adapt the course to fully online or blended learning.

Methods

To aid the current OC instructors in the FSUP in their efforts to systematically 1) identify the important features of laboratory activities with the aim of adapting them to distance learning and 2) assess the suitability of the curriculum for the training of forensic scientists, both were interviewed to elicit their views of their laboratory teaching. From the interviews, insights were extracted towards developing a viable and flexible—but no less rigorous—hybrid and/or online chemistry curriculum tailored for forensic scientists that, apart from hands-on laboratory experiences, could include interactive simulations, videos, animations, data sets, or at-home laboratory activities (Casanova, 2006). Questions were limited to the three laboratory activities completed before shutdown: a) "Intermolecular Forces and the Solubility of Substances"; b) "Reactivity of Alcohols", and c) "Acid-base Extraction of Organic Compounds". By choosing these activities, we were assured that both instructors had first-hand experience of guiding students through them. Interviews were conducted separately and recorded using a video conferencing tool.

To structure the interviews, three assessment instruments—designed to explore features of laboratory experiences from different perspectives—were chosen: 1) the Practical Activity Analysis Inventory (PAAI) (Millar, 2009); 2) the Competency Rubric Bank for the Sciences (CRBS) (Kishbaugh, 2012); and 3) the Meaningful Learning in the Laboratory Instrument (MLLI) (Galloway, 2005). Both instructors completed the PAAI for each of the three laboratory activities, as per the developer's instructions and without knowledge of the other's responses. For the CRBS and the MLLI, both were asked to rate the work carried out in the OC laboratory against the criteria set out by each instrument, applying a four-point Likert-type scale to each criterion, i.e., 1 = strongly disagree; 2 = disagree; 3 = agree; and 4 = strongly agree.

DOI: http://dx.doi.org/10.22201/fq.18708404e.2020.5.76857

The PAAI was chosen because it allows a thorough description of practical activities in general (of which laboratory work is only one kind) that can help to explore the effectiveness of activities in a systematic way, starting with the intended learning outcomes and ending with the extent to which students achieved them. The wide spectrum of competencies included in the CRBS, on the other hand, is especially relevant for forensic scientists, since their main tasks revolve around applying scientific research methods to the interdisciplinary study of criminal acts. Finally, the MLLI has a clearly articulated theoretical basis (Novak's Theory of Meaningful Learning) that goes beyond what students do to focus on how they think and feel in the laboratory, under the assumption that actions are influenced by cognitive and affective domains.

Results and discussion

For the sake of brevity, and because our chief aims are to establish a common starting point from which to assess the suitability of the OC curriculum taught to forensic scientists-in-training and gain insights into which aspects of laboratory work can be effectively shifted to distance learning, we focus on those aspects that both instructors agreed upon. Having said that, the disparities in their views are substantial enough to merit a more thorough exploration. (Their complete responses can be found in the Supporting Information.) Regarding the results from the PAAI, only those features that both instructors selected for at least two of the three laboratory activities were considered as shared features of OC instruction. In the case of the CRBS and the MLLI, for any given criterion, if both instructors selected a Likert rating of 1 or 2, the criterion was regarded as not likely to be part of laboratory activities. On the contrary, if both selected a rating of 3 or 4, the criterion was deemed likely to be.

Features of the laboratory activities used to teach Organic Chemistry

Box 1 summarizes the main features of the hands-on activities used to teach OC in the FSUP. The tasks identified as common to laboratory instruction center on the development of procedural skills that, collectively, aid students in understanding how scientific research is conducted: data collection, analysis, and presentation; compliance with standardized procedures; observation and explanation of phenomena and their properties, and manipulation of variables. Briefings before laboratory sessions tended to focus primarily on the equipment and procedures to be used—a topic consistent with the tasks that students were expected to perform. In light of the need to shift instruction to distance learning while simultaneously improving its fit to the skill set expected of forensic scientists, these findings pose an interesting dilemma. Given the emphasis placed on producing forensic graduates with a strong background on research methods, it is clearly essential for students to gain experience in the tasks listed above. However, in Mexico's criminal justice system, only certified chemists can legally carry out laboratory tests and present their conclusions in court. Forensic scientists might be called upon to request laboratory tests as part of a criminal investigation, but they will not be the ones performing them. This opens up the possibility of using non-laboratory-based teaching strategies (for example, Problem- or Project-Based Learning and case studies) to develop their background in research methods. Likewise, conceptual understanding of OC could be developed by simulations, analysis of data sets, or video recordings of demonstrations. Students could develop a satisfactory understanding of chemistry to request appropriate tests and explain their results to police, prosecutors, defense attorneys or judges without having enough expertise to perform the tests themselves. As important as technical skills might be for the training of chemists, their value for forensic scientists is secondary to an

Educación Química

understanding of the principles that underlie the chemical behavior of substances and materials, and how they are applied to the analysis of samples.

Even though both instructors believed that understanding scientific ideas was a fairly important aim of the work carried out in the OC laboratory, JLLZ prioritized the development of knowledge about the natural world (i.e., recalling patterns in observations; understanding concepts, models, or theories), while AVQ gave precedence to students learning how to use the equipment and follow standard procedures. These divergent views could be attributed to the instructors' number of years teaching OC courses (AVQ was in her first year as an OC instructor, whereas JLLZ has 17-years worth of experience teaching it) and their particular interpretations of the training needs of future forensic scientists. Although significant, in terms of the actual teaching in the OC laboratory, differing views about the aims to pursue are not particularly worrying, given the fact that the course is taught by two instructors, their viewpoints and experiences complementing one another.

Noteworthy among the skills where little to no agreement was reached, or were not even selected by the instructors, are those necessary for planning and conducting original research: identify good research questions; plan strategies for collecting data; design observation procedures; choose appropriate equipment; make or test predictions; explore how dependent variables change in relation to independent ones; discover patterns in data, and draw and assess conclusions. These omissions are consistent with the emphasis placed on technical proficiency. The omitted skills are notoriously hard to integrate into highly structured laboratory activities even though they are vital for forensic scientists; fortunately, they can be taught through activities compatible with distance learning.

Box 1. Features of the laboratory activities used in the Organic Chemistry laboratory as determined by the PAAI instrument

Listed below are those features that instructors deemed common to at least two of the three activities used in the term interrupted by Covid-19. In these activities, students:

- Should have developed an understanding of the scientific approach to inquiry.
- Collected data on a situation, then thought about how it might be summarized or explained.
- Followed a standard practical procedure.
- Made an event happen (produced a phenomenon).
- Observed an aspect or property of an object, material, or event.
- Reported observations using scientific terminology.
- Identified a similarity or difference (between objects, or materials, or events).
- Explored the effect or outcome of a specific change (e.g., using a different object, or material, or procedure).
- Decided if a given explanation applies to the particular situation observed.
- Suggested a possible explanation for data.

The activity—particularly its purpose or rationale—was explained to students:

- Orally by the teacher.
- Via written instructions on an overhead projector.
- Via a worksheet.

The class discussion before the activity centered on the equipment and procedures to be used.

Students recorded the results of the activity in a completed worksheet.

In all three activities, understanding scientific ideas was considered fairly important by instructors.

Educación Química
Experiencias sobre enseñanza remota | Páginas 3-14 | diciembre 2020
DOI: http://dx.doi.org/10.22201/fq.18708404e.2020.5.76857

Competencies exercised in the Organic Chemistry laboratory

Box 2 summarizes the key competencies that instructors agreed students had the opportunity to develop in the OC laboratory, as well as those they did not, according to the criteria set by the CRBS. The first group of competencies is made up of both practical skills—i.e., consider safety hazards and assess the accuracy and precision of data—and cognitive ones—organize ideas and express them orally—that are roughly consistent with the features the instructors agreed were common to at least two out of the three laboratory activities (see Box 1). Conversely, there is substantial overlap between the competencies in the second group—those not developed substantially—and the features in the PAAI that were not selected by both instructors—sometimes not even by one of them: for example, in the PAAI, only JLLZ believed that two of the laboratory activities could help students improve their understanding of scientific ideas, concepts, explanations, models, or theories. Moreover, in the instructors' opinion the activities do not offer students the opportunity to identify research questions; plan strategies for collecting data; and draw conclusions—competencies that were also not associated with the activities when assessed against the CRBS. Finally, application of the CRBS revealed that laboratory work does not foster an understanding of aspects of the nature of science and its societal relevance. This last point is relevant because the apparent emphasis placed on developing technical proficiency in the OC laboratory is unlikely to lead by itself to such an understanding: for example, being proficient at making observations does not make students aware of the theory-ladenness of observations—explicit instruction is be needed for that (Schwartz, 2004). Critically thinking about research methods is enhanced by philosophical awareness of how science works, and it would certainly strengthen the ability of forensic scientists to assess the quality of theirs' and others' research. As is the case for the skills included in the PAAI, the unexercised competencies in Box 2 could be developed by students through a distance learning approach.

The OC laboratory in the FSUP could address the need to increase students' exposure to more genuine and comprehensive research experiences by adopting, for instance, approaches like Cognitive Apprenticeship Theory as a tool to structure laboratory activities into a coherent whole that resembles actual scientific research (Stewart,2003).

Box 2. Competencies used in the laboratory activities used in Organic Chemistry laboratory as determined by the CRBS instrument

Instructors agreed students had the opportunity to develop or use the following competencies in the three laboratory activities:

- Consider safety hazards when handling materials and equipment.
- Evaluate the accuracy and precision of the data.
- Clearly and logically organize their ideas.
- Exercise their oral presentation skills.

Instructors agreed students had little to no opportunity to develop or use the following competencies in the three laboratory activities:

- Construct a well-developed understanding of scientific theories and concepts.
- Formulate clear research questions.
- Identify the rationale, hypothesis or systematic approach behind the activities.
- Reach conclusions that address the research questions.
- Articulate the scientific and societal relevance of the activity.
- Explicitly reflect on aspects of the nature of science, such as its empirical, tentative, inferential, theory-laden, and creative nature.

DOI: http://dx.doi.org/10.22201/fq.18708404e.2020.5.76857

Cognitive and affective domains addressed in the Organic Chemistry laboratory

The MLLI offers an alternative view of laboratory activities by focusing on their cognitive and affective domains. Box 3 shows that what students are most likely to think and feel in the laboratory relates to procedural aspects: the purpose of the procedures and the time available to perform them; the use of instruments, and the development of positive attitudes and work habits. On the other hand, what students are failing to experience in the laboratory extends to domains beyond mere technical expertise, consistent with the findings from the PAAI and the CRBS. DeKorver and Towns (2015) have already pointed out the lack of attention given to the affective domain in the laboratory (DeKorver, 2015), in spite of its influence on behavior and motivation. Particularly worrying, from the point of view of forensic science, is the lack of development of students’ critical thinking and problem-solving skills, crucial for planning and conducting research. As previously alluded to, forensic scientists are not being prepared to perform forensic chemists’ duties but, rather, to act as a liaison between scientific experts and justice operators. In this regard, understanding the underlying principles of chemical analysis is indispensable, especially when questions about the validity and reliability of results are relevant. Finding out that instructors believe students are unlikely to think about the behavior of molecules and relate it to observations—together with a lack of interest in the quality of data and in whether it makes sense—calls attention to the urgent need to reorient the curriculum—particularly that of OC—to areas better matched to the challenges forensic scientists are expected to face. Fortunately, these skills can also be taught remotely outside of laboratories. An inquiry-based approach could prove effective in promoting positive attitudes towards chemistry in the context of forensic science training (Sevian, 2012).

Box 3. Cognitive and affective experiences of students in Organic Chemistry Laboratory as determined by the MLLI instrument

Instructors agreed that, in laboratory activities, students were likely to:

- Worry about finishing on time.
- Feel unsure about the purpose of the procedures.
- Be confused about how the instruments work.
- Develop confidence in the laboratory.
- Make mistakes and try again.
- Be intrigued by the instruments.

Instructors agreed that, in laboratory activities, students were not likely to:

- Learn chemistry that will be useful in their lives.
- Experience moments of insight.
- Learn critical thinking skills.
- Be excited about chemistry.
- Consider if their data makes sense.
- Think about what molecules are doing.
- Worry about getting good data.
- Be nervous when handling chemicals.
- Think about chemistry that they already know.
- Worry about the quality of their data.
- Use their observations to understand the behavior of atoms and molecules.
- Be confident when using equipment.
- Learn problem solving skills.

Educación Química
Experiencias sobre enseñanza remota | Páginas 3-14 | diciembre 2020
DOI: http://dx.doi.org/10.22201/fq.18708404e.2020.5.76857

Conclusions

The COVID-19 pandemic has abruptly and dramatically changed teaching, and even if it proves to be a short-lived experience it is certain to leave long-lasting lessons. For courses with a sizeable laboratory component, the shift to distance learning is especially challenging, since materials and equipment become inaccessible. Such adverse conditions are forcing instructors to come to terms with the fact that developing some practical skills will not be possible until laboratory teaching is resumed. But they also offer the opportunity to reassess the value and role of the laboratory, particularly for programs where chemistry is taught as a subsidiary subject. Necessity turns into possibility.

In the FSUP taught at UNAM, chemistry subjects are meant to provide students with an understanding of the concepts and theoretical models that chemists use to plan, execute, and evaluate their research, with the ultimate aim of allowing forensic scientists to identify when chemical expertise is needed to investigate an allegedly criminal act. Such an understanding is also deemed essential for effective and accurate communication of the findings of a criminal investigation to other scientists, judicial operators, and lay persons. Any and all laboratory activities devised for the training of forensic scientists should deliberately aim at preparing them to fulfill their role as part of the criminal justice system. Attempting to improve the effectiveness of laboratory instruction and adapt it to distance learning can end up being an empty exercise if its aims are not carefully considered.

In 1970, Prosser (p. 19) asked his readers "whether the non-chemist students are receiving the type of guidance best suited to their interests and talents" (Prosser, 1970). This question is as valid and timely today as it was back then, and even more so when access to laboratories is restricted and inquiries are made about whether the high cost incurred by laboratory instruction is a worthwhile educational investment based on its effectiveness and its relevance for chemistry non-majors—as forensic scientists are (Hawkes, 2004).

Educación Química
Experiencias sobre enseñanza remota | Páginas 3-14 | diciembre 2020
DOI: http://dx.doi.org/10.22201/fq.18708404e.2020.5.76857

Practical Activity Analysis Inventory (PAAI)

	PRACTICALS	1		2		3		3B	
1.1	**Objectives (in general terms) and learning objectives (more specifically).**								
A	By doing the activity, students should develop their knowledge and understanding of the natural world.	1		1		1			
A1	Students can recall an observable feature of an object, or material, or event.								
A2	Students can recall a 'pattern' in observations (e.g. a similarity, difference, trend, relationship).					1			
A3	Students have a better understanding of a scientific idea, or concept, or explanation, or model, or theory.	1		1					
1.1	**By doing this activity, students should learn how to use a piece of laboratory equipment or follow a standard practical procedure.**								
B	By doing this activity, students should learn how to use a piece of laboratory equipment or follow a standard practical procedure.		1		1		1		
B1	Students can use a piece of equipment, or follow a practical procedure, that they have not previously met.								
B2	Students are better at using a piece of equipment, or following a practical procedure, that they have previously met.		1		1		1		
1.1	**By doing this activity, students should develop their understanding of the scientific approach to enquiry.**								
C	By doing this activity, students should develop their understanding of the scientific approach to enquiry.			0.5	0.5	0.5	0.5		✓
C1	Students have a better *general understanding* of scientific enquiry.						1		
C2	Students have a better *understanding of some specific aspects* of scientific enquiry.			1	1	1			✓
C2a	How to identify a good investigation question.								
C2b	How to plan a strategy for collecting data to address a question.					1			
C2c	How to choose equipment for an investigation.								
C2d	How to present data clearly.								
C2e	How to analyze data to reveal or display patterns.								
C2f	How to draw and present conclusions based on evidence.				1	1			
C2g	How to assess how confident you can be that a conclusion is correct.			1		1			
2.1	**Openness/closure**								
2.1.1	Question given, and detailed instructions on procedure.	1	1		1		1		✓
2.1.2	Question given, and outline guidance on procedure; some choice left to students.			1		1		1	
2.1.3	Students decide the question and how to proceed.								
2.2	**Logical structure of the activity**								
2.2.1	Collect data on a situation, then think about how it might be summarised or explained.	1	1	1	1	1	1		✓
2.2.2	Use your current ideas to generate a question or prediction; collect data to explore of test							1	
2.1.3	Other. Please describe:								
2.3	**Importance of an understanding of scientific ideas (to carry out the activity well)**								
2.3.1	Importance of an understanding of scientific ideas.	3	3	3	3	3	4	4	✓
2.4	**What students have to do with object and materials.**								
2.4.1	Use an observing or measuring instrument.						1		
2.4.2	Follow a standard practical procedure.	1	1	1	1	1	1		✓
2.4.3	Present or display an object or material.								
2.4.4	Make an object.								
2.4.5	Make a sample of a material or substance.						1		
2.4.6	Make an event happen (produce a phenomenon).	1	1	1	1	1	1		✓
2.4.7	Observe an aspect or property of an object, material, or event.	1	1	1	1	1	1		✓
2.4.8	Measure a quantity.		1		1		1		
2.5	**What students have to 'do' with ideas.**								
2.5.1.	Report observations using scientific terminology.	1	1	1	1	1	1		✓
2.5.2	Identify a similarity or difference (between objects, or materials, or events).	1	1	1	1	1	1		✓
2.5.3	Explore the effect of an outcome of a specific change (e.g. of using a different object, or material, or procedure)	1	1	1	1	1	1		✓
2.5.4	Explore how an outcome variable changes with time.				1				
2.5.5	Explore how an outcome variable changes when the value of a continuous independent variable changes.		1		1		1		
2.5.6	Explore how an outcome variable changes when each of two (or more) independent variables changes.						1		
2.5.7	Design a measurement or observation procedure.						1		
2.5.8	Obtain a value of a derived quantity (i.e. one that cannot be directly measured)						1		
2.5.9	Make and/or test a prediction.					1	1		✓
2.5.10	Decide if a given explanation applies to the particular situation observed.	1	1	1	1	1			✓
2.5.11	Decide which of two (or more) given explanations best fits the data.						1		
2.5.12	Suggest a possible explanation for data.	1	1	1	1	1	1		✓
3.1	**How is the purpose, or rationale, communicated to students?**								
3.1.1	Activity is proposed by teacher; no explicit links made to previous work.		1		1		1		
3.1.2	Purpose of activity explained by teacher, and explicitly linked to preceding work.	1					1		
3.1.3	Teacher uses class discussion to help students see how the activity can help answer a question of interest.			1		1	1		✓
3.1.4	Purpose for activity readily apparent to the students; clearly follows from previous work.								
3.1.5	Activity is proposed and specified by the students, following discussion.								
3.2	**How is the activity explained to students?**								
3.2.1	Orally by the teacher.	1	1	1	1	1	1		✓
3.2.2	Written instructions on OHP or data projector.	1	1	1	1	1	1		✓
3.2.3	Worksheet.	1	1	1	1		1		✓
3.2.4	(All or part of) procedure demonstrated by teacher beforehand.								
3.3	**Whole class discussion before the practical activity begins?**								
3.3.1	None.								
3.3.2	About equipment and procedures to be used.	1	1	1	1	1	1		✓
3.3.3	About ideas, concepts, theories, and models that are relevant to the activity.	1		1		1			
3.3.4	About aspects of scientific enquiry that relate to the activity.						1		
3.4	**Whole class discussion following the practical activity?**								
3.4.1	None.		1		1				
3.4.2	About confirming 'what we have seen'.						1		
3.4.3	Centered around a demonstration in which the teacher repeats the practical activity.								
3.4.4	About how to explain observations, and to develop conceptual ideas that relate to the task.	1		1		1			
3.4.5	About aspects of investigation design, quality of data, confidence in conclusions, etc.			1		1	1		✓
3.5	**Students' record of the activity**								
3.5.1	None.								
3.5.2	Notes, as the student wishes.								
3.5.3	A completed worksheet.	1	1	1	1		1		✓
3.5.4	Written report with a given structure and format.		1		1	1	1		✓
3.5.5	Written report in a format chosen by the student.								
4	**Learning demand.**								

Supplementary Fig. 1. PAAI. Complete responses of the two instructors to the Practical Activity Analysis Inventory assessment instrument. Both instructors completed the PAAI for each of the three laboratory activities (1, 2, 3 and 3B), as per the developer's instructions and without knowledge of the other's responses. Both were asked to rate the work carried out in the OC laboratory against the criteria set out by the instrument, deciding dichotomously whether a given criterion was met (signaled by a value of “1”) or not. Each instructor is represented by a color (red and blue) and on the criteria where there was agreement, a (✓) is placed next to the column.

DOI: http://dx.doi.org/10.22201/fq.18708404e.2020.5.76857

Competency Rubric Bank for the Sciences (CRBS)

Content Knowledge: Accuracy of scientific understanding.	2	2	LOW	✓
Analysis: Clarity of Research Question.	1	2.5	LOW	✓
Analysis: Identifies Rationale, Hypothesis, or Systematic Approach.	1	2.5	LOW	✓
Synthesis: Design of Methology.	1	3	SPLIT	✗
Application: Safety and Ethical Considerations.	4	4	HIGH	✓
Application and analysis: Data Collection and Analysis.	1	3	SPLIT	✗
Application: Data Presentation.	2	4	SPLIT	✗
Synthesis: Conclusions.	1	2.5	LOW	✓
Evaluation: Accuracy & Precision.	3	3	HIGH	✓
Evaluation: Relevance. **NOS:** Social and Cultural Nature of Science. **Understandings:** Science is a human enterprise, practiced within and affecting society and culture.	1	1	LOW	✓
Organization & Sequence.	4	3	HIGH	✓
Writing Conventions.	4	2.5	SPLIT	✗
Oral Presentation Skills.	4	3.5	HIGH	✓
Empirical NOS: Scientific knowledge is based on and/or derived from observations of the natural world (data).	1	1	LOW	✓
Tentative NOS: Scientific knowledge is subject to change with new observations and with the reinterpretations of existing observations. Scientific knowledge is not absolute nor certain.	1	1	LOW	✓
Inferential NOS: Scientific knowledge is based on both observation and inference. There is a critical distinction between scientific claims (e.g., inferences) and evidence on which claims are based (e.g., observations).	1	1	LOW	✓
Theory-laden NOS: Scientific knowledge and investigation are influenced by scientists' theoretical and disciplinary commitments. Because scientific knowledge is theory-laden, there is an unavoidable subjectivity to science.	1	1	LOW	✓
Myth of the "Scientific Method": There is no universal stepwise method that guarantees the generation of valid scientific knowledge. Many different methodologies are valid means of scientific formation, and contribute together to validate a hypothesis.	1	1	LOW	✓
Creative NOS: Science is a creative process, not completely rational, lifeless and orderly. In this manner, there is an unavoidable subjectivity in science. Thus, scientific concepts, such as atoms or species, are useful models, not perfect copies of reality.	1	1	LOW	✓
Social and Cultural NOS: Science is a human enterprise, practiced within and affecting society and culture. Scientists are influenced by culture - in their beliefs, values, norms, and prior knowledge (thus, scientific knowledge is somewhat subjective). The scientific community is a culture into itself, with its own norms and values, and systems of approving knowledge.	1	1	LOW	✓

✓	16	80	%
✓	0	0	%
✗	4	20	%
	20	**100**	**%**

Supplementary Fig. 2. CRBS. Complete responses of the two instructors to the Competency Rubric Bank for the Sciences assessment instrument. Both instructors were asked to rate the work carried out in the OC laboratory against the criteria set out by each instrument, applying a four-point Likert-type scale to each criterion, i.e., 1= strongly disagree; 2 = disagree; 3 = agree; and 4 = strongly agree. Each instructor is represented by a color (red and blue) and the criteria where there was agreement is identified by a (✓) next to the column; when there was no agreement, a (X) appears next to the column.

Educación Química

Meaningful Learning in the Laboratory Instrument (MLLI)

1	C/A	+	to learn chemistry that will be useful in my life.	1	2	LOW	✓
2	A	-	to worry about finishing on time.	4	4	HIGH	✓
3	C	+	to make decisions about what data to collect.	2	3	MEDIUM	✓
4	C/A	-	to feel unsure about the purpose of the procedures.	4	4	HIGH	✓
5	C	+	to experience moments of insight.	2	2.5	LOW	✓
6	C	-	to be confused about how the instruments work.	4	3.5	HIGH	✓
7	C	+	to learn critical thinking skills.	2	2.5	LOW	✓
8	A	+	to be excited to do chemistry.	2	3.5	MEDIUM	✓
9	A	-	to be nervous about making mistakes.	2	3.5	MEDIUM	✓
10	C	+	to consider if my data makes sense.	2	2.5	LOW	✓
11	C	+	to think about what the molecules are doing.	1	2.5	LOW	✓
12	C/A	-	to feel disorganized.	3	2	MEDIUM	✓
13	A	+	to develop confidence in the laboratory.	3	3	HIGH	✓
14	C/A	-	to worry about getting good data.	2	2.5	LOW	✓
15	C	-	the procedures to be simple to do.	3	1	SPLIT	✗
16	C	-	to be confused about the underlying concepts.	1.5	3	SPLIT	✗
17	C	+	to "get stuck" but keep trying.	3	2.5	MEDIUM	✓
18	A	-	to be nervous when handling chemicals.	2.5	2	LOW	✓
19	C	+	to think about chemistry I already know.	1	2.5	LOW	✓
20	C/A	-	to worry about the quality of my data.	2	2.5	LOW	✓
21	A	-	to be frustrated.	1	3	SPLIT	✗
22	C	+	to interpret my data beyond doing only calculations.	1	3.5	SPLIT	✗
24	C	-	to focus on procedures, not concepts.	1	4	SPLIT	✗
25	C	+	to use my observations to understand the behavior of atoms and molecules.	1	2	LOW	✓
26	C	+	to make mistakes and try again.	3	3	HIGH	✓
27	C/A	+	to be intrigued by the instruments.	3	3.5	HIGH	✓
28	A	-	to feel intimidated.	1	3	SPLIT	✗
29	C	-	to be confused about what my data mean.	2.5	3.5	SPLIT	✗
30	A	+	to be confident when using equipment.	2.5	2	LOW	✓
31	C	+	to learn problem solving skills.	2	2	LOW	✓

✓	18	60	%
✓	5	17	%
✗	7	23	%
	30	100	%

Supplementary Fig. 3. MLLI. Complete responses of the two instructors to the Meaningful Learning in the Laboratory Instrument (MLLI). Each instructor is represented by a color (red and blue). When both respondents chose 1 or 2, they were awarded LOW belief in the proposition (✓). When both respondents chose 3 or 4, they were awarded HIGH belief in the proposition (✓). When one respondent chose 1 or 2 and the other respondent chose a 3 or 4, they were awarded a MEDIUM belief in the proposition (✓). When the difference between respondents scores is = or > 2, they were awarded a SPLIT belief in the proposition (X).

References

Arnaud, C. H. Questioning the Value of General Chemistry Labs. *https://cen.acs.org/education/undergraduate-education/Questioning-value-general-chemistry-labs/98/i18* (accessed, Jun 10, 2020).

Bell, S. Forensic Chemistry. *Annu. Rev. Anal. Chem.* 2009, *2*, 297-319.

Bell, S. *Forensic Chemistry*, 2nd ed.; Pearson Education Limited: Harlow, United Kingdom, 2014; p 9.

Bretz, S. L. Evidence of the Importance of Laboratory Courses. *J. Chem. Ed*. 2019, *96*, 193-195.

Casanova, R. S.; Civelli, J. L.; Kimbrough, D. R.; Heath, B. P.; Reeves, J. H. Distance Learning: A Viable Alternative to the

Conventional Lecture-Lab Format in General Chemistry. *J. Chem. Ed*. 2006, *83*, 501-507.

DeKorver, B. K.; Towns, M. H. General Chemistry Students' Goals for Chemistry Laboratory Coursework. *J. Chem. Educ.* 2015, *92*(12), 2031-2037.

Facultad de Medicina. *Plan de Estudios de la Licenciatura en Ciencia Forense*; Universidad Nacional Autónoma de México: Mexico City, 2013; pp 2-7, 19, 37-45.

Forensic Science Undergraduate Programme in a Nutshell. *http://www.cienciaforense.facmed.unam.mx/wp-content/uploads/2015/02/ForensicScienceUndergraduateProgramme.pdf* (accessed, Jun 9, 2020).

Galloway, K. R.; Bretz, S. L. Development of an Assessment Tool to Measure Students' Meaningful Learning in the Undergraduate Chemistry Laboratory. *J. Chem. Ed*. 2015, *92*, 1149-1158.

Hawkes, S. J. Chemistry Is *Not* a Laboratory Science. *J. Chem. Educ*. 2004, *81*, 1257.

Kishbaugh, T. L. S.; Cessna, S.; Horst, S. J.; Leaman, L.; Flanagan, T.; Neufeld, D. G.; Siderhurst, M. Measuring Beyond Content: A Rubric Bank for Assessing Skills in Authentic Research Assignments in the Sciences. *Chem. Educ. Res. Pract*. 2012, *13*, 268-276.

Lee, B.; Renwick, D.; Cara Labrador, R. Mexico's Drug War/Council on Foreign Relations. https://www.cfr.org/backgrounder/mexicos-drug-war (accessed Jun 9, 2020).

Millar, R. *Practical Activities Analysis to Assess and Improve Effectiveness: The Practical Activity Inventory (PAAI)*; Centre for Innovation and Research in Science Education, University of York: York, United Kingdom, 2009.

Prosser, A. P. Teaching Chemistry as a Subsidiary Subject. *The Vocational Aspect of Education*, 1970, *22*(51), 19-23.

Samarji, A. Forensic Science Education: Inquiry into Current Tertiary Forensic Science Courses. *Forensic Science Policy & Management*. 2012, *3*, 24-36.

Schwartz, R. S.; Lederman, N. G.; Crawford, B. A. Developing Views of the Nature of Science in an Authentic Context: An Explicit Approach to Bridging the Gap between Nature of Science and Scientific Inquiry. *Science Education*. 2004, *88*(4), 610-645.

Sevian, H.; Fulmer, G. W. Student Outcomes from Innovations in Undergraduate Chemistry Laboratory Learning: A Review of Projects Funded by the US National Science Foundation between 2000-2008. *Educación Química*, 2012, *23*, 149-161. http://www.scielo.org.mx/pdf/eq/v23s1/v23s1a8.pdf

Stewart, K. K.; Lagowski, J. J. Cognitive Apprenticeship Theory and Graduate Chemistry Education. *J. Chem. Educ*. 2003, *80*, 1362–1366.