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Is It a Good Idea for Chemistry and Sustainability Classes to Include Industry Visits as Learning Outside the Classroom? An Initial Perspective

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Abstract: Learning outside the classroom (LOtC) activities are part of pedagogical methodologies that are currently applied in the development of student skills. The objective of this study is to determine the perceptions of faculty and undergraduate students concerning industrial visits and define the advantages and disadvantages of these activities. A survey was designed with 17 questions, from a sample of 296 students and 32 professors from various chemistry and sustainability courses. The statistical samples correspond to a population of 2275 students and 246 professors. Descriptive statistics were used to analyze and compare participant perceptions on industrial visits, as LOtC activities. Results indicated a positive perception for making industrial visits, generating more interest in the class material and helping students acquire knowledge. Despite this positive perception, it was found that professors are unlikely to organize industrial visits frequently due to the work required to plan, perform, and evaluate these activities. This issue suggests that approximately 40% of the students may lose the advantages that LOtC activities could offer. Professors must be motivated and supported by administrators to include industrial visits in their courses as a teaching strategy to provide a beneficial experience to the majority of students enrolled in chemistry and sustainability undergraduate programs.

Keywords: learning outside the classroom (LOtC); industrial visits; STEM education; education for sustainable development; educational innovation; higher education



Citation: González-Peña, O.I.; Peña-Ortiz, M.O.; Morán-Soto, G. Is It a Good Idea for Chemistry and Sustainability Classes to Include Industry Visits as Learning Outside the Classroom? An Initial Perspective. *Sustainability* **2021**, *13*, 752. <https://doi.org/10.3390/su13020752>

Received: 17 December 2020

Accepted: 12 January 2021

Published: 14 January 2021

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1. Introduction

It is common for instructors, nowadays, to use different methodologies and pedagogical strategies to encourage their students to develop skills that will serve them in their academic and professional performances. One of the most utilized methods to promote better learning outcomes is known as learning outside the classroom (LOtC). This method has become popular at different educational levels. It can be used through teaching strategies, such as the inverted classroom [1], problem-based or project-based learning [2], professional practices [3], or industrial visits [4], among others. Educators use these pedagogical practices related to LOtC to inform, teach, and motivate students to develop a greater interest in course content [5]. As a result, using these pedagogical tools contributes to the development of the cognitive skills necessary to train professionals to face the most pressing challenges around the world [6].

Likewise, in the decade of 90s, the American Association for the Advancement of Science [7], the National Research Council [8], and the National Science Foundation (NSF) began using Sciences, Technology, Engineering, and Mathematics (STEM), with the intention of promoting and categorizing different activities, programs, and public policies,

where the disciplines of Sciences, Technology, Engineering, and Mathematics (STEM) intervene. Therefore, with the term STEM, it was sought, among other things, to encourage innovation and problem solving in the educational system [9]. However, later in the next decade (2000–2010), there was still little use (or confusion) for the term STEM. Thus, in 2009, the National Assessment of Educational Progress (NAEP) in engineering began evaluating technology literacy in the U.S. [9–11]. In 2010 and 2014, initiatives to promote technology and engineering education were launched by the National Assessment Governing Board (NAGB) to include social problems related to STEM issues, such as: energy efficiency, climate change, sustainability, etc. [9,12]. In parallel, the framework for The Programme for International Student Assessment (PISA) 2006 [13] was structured. As a result, they included, in curricular subjects, the relevance of studying in local, regional, and global context issues, such as: health, energy efficiency, natural resources, environmental quality, hazard mitigation, etc. [9,13]. Furthermore, among the different educational activities, the LOtC method has been listed as a recommended tool for students and instructors in the United Nations Educational, Scientific, and Cultural Organization (UNESCO) program: Teaching and Learning for a Sustainable Future [14,15]. The United Nations is actively contributing to the design and development of educational processes that could help students understand the importance of creating technological solutions in a sustainable way. One of the most relevant projects of the United Nations is the program: Teaching and Learning for a Sustainable Future, which is a multimedia program focused on training instructors in education for sustainable development. The United Nations Educational, Scientific, and Cultural Organization (UNESCO) has shown particular interest in sustainable development, presenting a report in relation to the final monitoring and evaluation of the decade of education for sustainable development [16,17]. This report shows that many education systems around the world are making efforts to address sustainability issues, aiming to confront social, environmental, and economic challenges in a more sustainable way. These efforts to address sustainability issues could be seen at the secondary level [18], basic vocational education [19], or universities that need to assess whether their programs are strongly involved in linking student curricula with the general objectives of sustainable development [20]. This growing interest, in teaching students and professionals about sustainable development goals, could be addressed in a better way if professors included LOtC to facilitate their students' active learning. In this sense, there have been examples of courses that have included hands-on activities with the goal of developing sustainable projects, such as building prototypes of powered cars without internal combustion in one-week projects [21], or full semester projects [22]. These LOtC methods could promote student interest in sustainable development, especially if these methods could show them the most relevant environmental issues in their locality, and how industries are looking for solutions to improve the sustainability of their processes.

Although learning experiences outside the classrooms have resulted in better development of student skills [6,23], complications have arisen while planning implementation of these strategies in schools. Among the primary complications: schools must have trained staff as well as an infrastructure that allows students to explore outside the classroom. These basic requirements of learning methodologies outside the classroom are often missing, making it difficult to apply and adapt these LOtC activities to classes in public educational institutions and developing countries [24]. Our research was intended to complement the existing literature on LOtC by determining the perception of undergraduate chemistry students, and their professors, on visits to companies or industries. Likewise, this study is relevant due to its aim to find a more structured way to plan and evaluate the impact of industrial visits on students and professors. In the end, the results of this research can be the basis for programming future industrial visits by university students and, possibly, generate more studies on this learning strategy.

2. Purpose of This Study

The analysis of existing literature on LOtC techniques found that most studies obtained their data from a single part of the teaching process, based on information collected from students, without considering the instructors. Or vice versa—they took into account the opinions of professors without collecting information on students. This study seeks to supplement the current literature on LOtC by establishing reflection and integration of learning experiences that take place outside of the classroom. Moreover, this research focus on industrial visits, seeking to complement the existing LOtC literature by interpreting the opinions on these visits by both students and university professors in chemistry and sustainability areas not previously reported, according to the bibliographic search carried out in this study. Therefore, this work is relevant because there is currently no information that can help college educators organize and evaluate these activities in a standardized way, and these missing parts may negatively affect the outcome of these industrial visits. To achieve the purpose of this study, we posed the following research questions to guide our work:

- What perceptions do undergraduate students, enrolled in majors related to chemistry and sustainability, have on industrial visits?
- What perceptions do university professors, who teach chemistry and sustainability courses, have on industrial visits?
- What are the advantages and disadvantages of industrial visits in the teaching processes of college-level chemistry and sustainability courses?

3. Theoretical Framework

This research is based on the out-of-classroom learning methodologies reported in the “Learning Outside the Classroom” manifesto published by the Department for Education and Skills in United Kingdom [25]. This manifest indicates that young people should experience the world beyond the classroom as an essential part of their learning and personal development. Therefore, studies that motivate professors can be found to encourage children and adolescents to learn outside of the classroom [5]. Literature recognizes that learning strategies outside of the classroom provide students with opportunities to develop skills—much better than just experiencing a classic classroom education; in this way, outside activities complement in-classroom instructions [2].

It is important to mention that, for LOtC strategies to be effective, and motivate students to take an interest in the class, these strategies must have well-thought-out goals from the outset, as well as clear objectives and tasks that can be accomplished in a set time frame [26]. If outside learning strategies are planned considering these indications, students will likely be able to use what they have learned outside of the classroom in all kinds of school activities, as well as in daily life. In the end, students will fortify their interests in learning and studying new topics by performing activities, such as field trips, laboratories, inverted classrooms, and industrial visits, among others [27].

As the goal of the United Nations Education for Sustainable Development is to improve access to education in order to transform society in a sustainable way, they support activities that help instructors incorporate education for sustainable development into teaching and learning activities [16]. This support for more education (for sustainable development) could positively influence school administrators and stakeholders to promote public policies at global, national, and regional levels; creating better possibilities of an alignment of visions and goals, at all educational levels, with a long-term plan for sustainable development.

4. Previous Studies

Undergraduate STEM programs are usually missing a strong link to educate students in a cooperative effort between academia and industry to excel in their new jobs. In this sense, [28] found that stimulation, in the innovative behavior, can be enhanced by LOtC activities that promotes student learning, self-efficacy, and career planning. A wide

variety of studies can be found that use LOtC strategies with all types of students around the world. Studies on adolescents reported better development of their emotional and social skills and attributes when using activities related to LOtC [29]. Elementary and secondary school students reported better development of their social interactions and showed better communication and collaboration with classmates when their instructors used LOtC strategies [24,30]. In addition to the benefits of social interaction, the activities that take place outside of the classroom, in outdoor environments, can improve the concept of personal values, such as freedom, fun, autonomy, and a sense of satisfaction, which promotes the integral development of children [5].

Pedagogical outings are different LOtC strategies. These pedagogical outings allow students the opportunity to deal with different contexts, areas, or fields of study, where there are not enough educational resources to develop a subject extensively as in a classroom setting [4]. In these outings, learning opportunities come from having direct experiences with the phenomenon under study, motivating students to ask questions and get involved in research projects that could provide students with better educational and social abilities [31].

Other studies have used the project-based learning strategy for teaching outside of the classroom in high school courses. These studies suggest that collaborative project-based-learning could result in better academic performance, facilitating the exchange of ideas among all the team members during the planning and elaboration of the project [32]. The project-based learning strategy could be considered as a good LOtC activity after an industrial visit, as professors and students learn more about solving real-life problems. In addition, options, such as lab practices, do not require a student to leave the school to apply learning strategies, similar to those outside of the classroom. These types of practices are widely used in chemistry courses with positive effects on students' motivation [33,34].

In general, activities outside of the classroom involve connecting knowledge acquired in the classroom to information and applications used in different environments, allowing students to develop important abilities that facilitate their critical thinking development. This way of creating and developing knowledge can be related to the constructivist theory of meaningful learning. This theory describes that prior knowledge constitutes the basis for new knowledge, as long as there is a logical relationship between them [35]. The knowledge obtained through learning outside of the classroom uses previously acquired knowledge to experiment and draw conclusions, which help develop and expand the body of knowledge [36].

Concerning college students, examples of various LOtC methods that are used for teaching STEM can be found, where the objective is that students develop autonomous and critical thinking. It has been found that project evaluation can help students develop interdisciplinary and specific competencies, allowing them to know what their roles are or what might be their participation within the industrial sector [37]. Other activities, such as fieldwork, allow students the opportunity to analyze and assess issues related to the quality of the products and services in the current market [38]. In addition, these LOtC strategies have proven to have a positive impact on the development of students' study, communication, and scientific writing skills [33], as well as the interests they take in their courses [1,39]. Moreover, LOtC strategies can facilitate the application of previously learned knowledge, helping students manage a higher level of cognitive processing [40,41]. Other studies have associated college-level course development with the industry, including talks, and research projects with sponsorships [42]. Other options include offering one-year positions in different industries [43], and promoting regular industrial visits to different companies, where students can disassemble and assemble industrial machines [44,45].

Another approach that has been sought to achieve LOtC is to use computational tools, such as virtual reality [46] or gamification [47]. In one virtual reality environment, students participated in emulating an iron-making industrial visit; therefore, this study presents a method of avoiding the possible disadvantages of costs, transportation, and high standards of industrial safety that are typically involved in student industrial visits [46]. Moreover,

using gamification as a LOtC activity showed that this method works well at promoting enjoyment with learning—with better performance—when students are evaluated using games as a learning tool [47].

Despite the advantages that LOtC methods have shown concerning the development of student knowledge and abilities, few studies have registered evidence of college-level science courses that incorporate these strategies as a teaching method. Previous studies that analyzed industrial visits in college courses have found that both students and professors consider these industrial visits as positive experiences that facilitate student learning. The issue with these studies is that their main goal is to analyze student learning activities in general, and they are not focused on industrial visits [38,48,49].

Literature suggests that most college students have not experienced industrial visits or any other LOtC activity [49]. This could stem from the lack of well-structured plans from universities to implement these didactic strategies [50]. The lack of opportunities to learn using outside of the classroom strategies in university courses could ultimately affect student development [51]. In addition to losing opportunities to improve academically, students without LOtC experiences also miss opportunities to develop as professionals with social commitments [3].

Regarding chemistry, it has been pointed out that cognitive skills that can be developed with LOtC strategies are essential for performing scientific processes and laboratory work. The skills developed with these strategies allow students to reflect on the topics learned and how they learn those things, giving them the tools needed to transfer knowledge beyond the classroom [32,52]. Students in chemistry-related careers need to develop skills to apply theoretical learning, to practice in the laboratory, and solve problems in their working lives [53]. For this reason, professional programs in universities should try to incorporate more activities connected with industry and research in the areas of chemistry.

The incorporation of teaching outside of the classroom in college chemistry courses can also serve as a networking bridge for universities with businesses. For example, industrial visits could facilitate students' professional training so they can graduate from college equipped with better skills to solve problems presented in the industrial sector [54,55]. This academic–industry link not only includes the possible resolution of industrial problems, but also the development of better oral and written communication skills due to the direct contact with potential future employers [56]. Another advantage of incorporating LOtC strategies into college chemistry courses is that these experiences could have a positive impact on students' interest in continuing with graduate studies [57]. This is because students obtain access to all types of resources and professionals that might help them identify topics of their interest in the study of chemistry, which may ultimately motivate them to consider the possibility of becoming researchers or scientists in these subjects [57].

5. Methods

This research was based on a multi-method approach (see Figure 1), conducting a qualitative phase followed by a quantitative phase [58]. For the qualitative phase, a survey was developed with the goal of collecting data about visits to the chemistry industry. This survey was developed after the authors could not find a validated instrument on a survey that collected data on this specific topic in the current literature. Hence, a new instrument was designed to facilitate information gathering about industrial visits, related to the teaching of sustainability and chemistry related courses. The design of the new instrument began with a search to find the key questions that should be included in a survey, to understand how students and professors from sustainability and chemistry related majors perceived such visits. Semi-structured interviews were conducted with two chemistry professors who had several years of experience utilizing industrial visits in their courses. During the interviews, open-ended questions were asked that allowed the professors to discuss their positive and negative experiences during their visits to industries connected with chemical processes [59]. The two interviews were audio-recorded and transcribed for

analysis. Each interview was coded line-by-line through an open coding strategy similar to that used in grounded theory methodology [60].

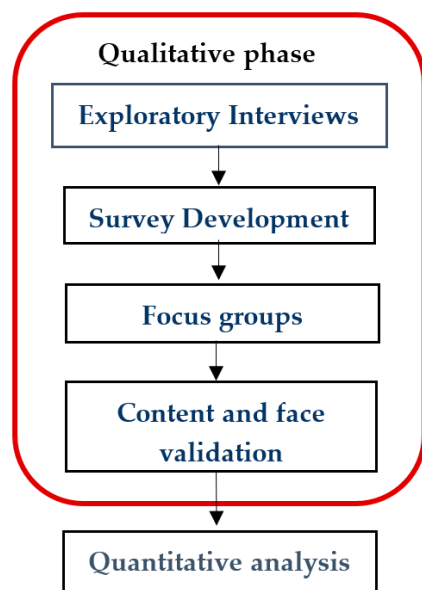


Figure 1. Multi-methods research design.

This qualitative analysis strategy allowed researchers to find themes and meaning units that served as the basis for our survey questions [61,62]. Seventeen multiple-choice questions were drafted in Spanish to determine the frequency, possible impediments, and reasons for making industrial visits. Two focus groups were put together to test the content and wording of the new instrument questions [63]. The first focus group consisted of four professors from different chemistry courses, and the second of ten students in various chemistry programs in the university where this research was conducted. During the focus groups, participants were asked to read the questions and possible answers, to give their feedback about the clarity of the statements, and identify possible misunderstandings in the content of the survey [25]. In the end, some questions were modified for clarity according to the feedback received by chemistry students and professors. In particular, questions 1–7 and 16 were designed to be similar for students and professors. Additionally, questions 8, 13, 14, and 15 were labeled as professors' questions because it did not make sense to ask those types of questions to students. Questions 9, 10, 11, 12, and 17 were designed to be answered for students and professors, but syntax was required to be different in the structure of the questions, to be separated; this means that those questions had subtagging: (I) for student and (II) for professors. In other words, the information gathered was the same for both groups (please refer to the Appendix A to see the questionnaire).

After the content and face validation process [25], the survey with 17 questions was distributed on paper. This survey was translated to English by one of the researchers for publication purposes only (see Appendix A). The information was collected from a sample of 296 undergraduate students and 32 professors in chemistry-related bachelor's programs during the fall semester of 2016 at a public university in the state of Jalisco, Mexico. For context, Jalisco is one of the most important industrial states in the country, with a value of sales of manufactured products of \$400,641,994 (thousands of Mexican pesos, MXN) [64]. The main productive activities in the state of Jalisco include industry sectors, such as steel, mechanical, textile, computers manufacturing, communication, measurement equipment and other electronic equipment, components, and accessories [65]. However, there are also relevant and considerable industrial activities in the region, such as food, beverages and tobacco, tanning and leather or substitute materials, paper, plastic, and rubber industry, chemical industry, transport equipment manufacturing, metal products, and basic metal industries, among others [64]. Due to this high and diverse industrial activity, the state of

Jalisco is also considered one of the main polluting areas in Mexico. This region generates high polluting emissions in the air, water, and soil. Mexican environmental regulations are currently aiming to facilitate the efficient classification and management of all waste and emissions. This is where industrial visits could help universities develop curricula that consider the current needs and regulations that all chemical processes need to fulfill for appropriate waste management, at a laboratory scale and beyond [66].

Both professors and students were instructed to answer the questions labeled with their descriptions, or not labeled at all, avoiding the questions labeled with a role that did not match their own role in the class (professors avoided questions designed for students, and vice versa, students avoided questions designed for professors). These special instructions resulted in several questions that were not answered because they were designed for a different context for that particular participant (see Appendix A). The size of the sample obtained was larger than that determined by the formula shown below [67]:

$$n = \frac{pqNz_{\alpha}^2}{(N-1)d^2 + pqz_{\alpha}^2} \quad (1)$$

z_{α}^2 is a statistical parameter that depends on N ; $q = (1 - p)$ is the probability that the event will not occur; d is the accepted estimation error; p is the fraction or proportion of the elements in the sample that possesses the characteristic of interest. n and N represent the sample size and the target population, respectively.

Students in the sample were enrolled from first through fourth semesters of the bachelor's degree programs in chemistry, chemical engineering, and chemical pharmacobiology, and were between 19 and 21 years old. The sample of professors normally taught subjects in the area of sustainability and chemistry, such as general chemistry, physical-chemistry, chemistry of the cell (biochemistry), environmental chemistry (environmental pollution), and analytic chemistry. They had 15 to 25 years of experience as university professors. Students and professors, in this sample, were purposely selected from chemistry courses that were required to be taken by students during the first four semesters of their major in the university where the study was conducted. This sampling strategy facilitated data collection since students from fifth or higher semesters usually have flexibility of their curricula in chemistry majors that no longer require mandatory chemistry courses. The surveys were distributed and collected during student class time. Subsequently, survey responses were digitalized to conduct the statistical analysis.

For the quantitative analysis, the responses of professors and students were analyzed separately. Additionally, data from students and professors were separated into two more groups for better interpretation of the information collected. The first two groups contained students and professors who had experienced industrial visits in the past, while the additional two groups contained students and professors who had never experienced industrial visits (see Table 1). As a result, four groups were analyzed in separate ways; the first group clustered students with industrial visit experiences; the second group clustered professors with industrial visit experiences; the third group clustered students without industrial visit experiences; and the fourth group clustered professors without industrial visit experiences (see Table 1). These groups facilitated the analysis of the data and allowed a better interpretation of the results. For the data analysis, tables and graphs were assembled with the data from each of the questions separately. Responses of students and professors were compared in all four groups to contrast the answers according to their experience with industrial visits. Finally, these tables and graphs of the four groups were compared side-by-side to determine possible differences or similarities between the professors' and students' opinions on industrial visits, to answer the research questions adequately.

Table 1. Industrial visits made by students and professors.

	None	One or More Visits
Students (<i>n</i> = 296)	115 (39%)	181 (61%)
Professors (<i>n</i> = 32)	14 (44%)	18 (56%)

6. Results and Discussion

Table 1 presents the groups made up of professors and chemistry students who made none, or at least one, industrial visit in their college curricula.

Of the 181 students who reported having made an industrial visit during their course work, 150 (83%) reported that their greatest motivation to accept the invitation for an industrial visit was to develop knowledge, and be up-to-date with the methods and procedures currently used in the chemistry industry. The analysis of the same question to the 18 professors who had organized one or more industrial visits revealed that 17 (94%) of them responded that their greatest motivation to organize the visit was to reinforce the learning of their students, and ensure that they were up-to-date with the processes currently used in the chemistry industry.

On the other hand, the professors and students who had never made an industrial visit gave very different answers to the question about why they had not participated in industrial visits during their university studies. Of the 115 students who had not made an industrial visit, 77 (67%) reported not receiving an invitation from the professors or university. The professor responses showed that the majority of the 14 professors who had not organized industrial visits had not been involved in this learning activity outside the classroom due to a lack of time (12 of the 14 professors (86%) gave this response).

The results displayed in Table 2 show the semester that the students and professors consider most appropriate to visit a chemistry-related industrial visit.

Table 2. Semesters in which chemistry professors and students prefer to make industrial visits.

	First	Second	Third	Fourth or Later
Students				
With experience in industrial visits	43 (24%)	32 (18%)	68 (37%)	38 (21%)
Without experience in industrial visits	30 (26%)	30 (26%)	30 (26%)	25 (22%)
Professors				
With experience in industrial visits	9 (50%)	5 (28%)	4 (22%)	0 (0%)
Without experience in industrial visits	7 (50%)	4 (29%)	2 (14%)	1 (7%)

In addition to the semester preference indicated for making industrial visits shown in Table 2, 91% of all students reported that they would like to make an industrial visit every semester. In comparison, 91% of the professors prefer these learning activities outside of the classroom to be programmed more sporadically, with only one industrial visit programmed throughout their students' university careers, or one every one or two years.

Table 3 shows the number of students and professors who made an industrial visit, and whether they had a clear objective of what they sought to achieve visiting a specific industry.

Table 3. Number of students and professors with a clear objective in their industrial visits.

	They Began with a Clear Objective	They Did not Begin with a Clear Objective
Students	142 (78%)	39 (22%)
Professors	18 (100%)	0 (0%)

As a complement to the results shown in Table 3, 92% of students who had made an industrial visit reported that they already had an idea of what they would see in the industry prior to their visit. On the professors' side, 100% of them who had already made

an industrial visit indicated that they already knew what was in the chemistry industry before visiting it.

The majority of students who had made industrial visits reported that this learning strategy outside of the classroom helped them improve their knowledge of chemistry-related topics (see Figure 2).

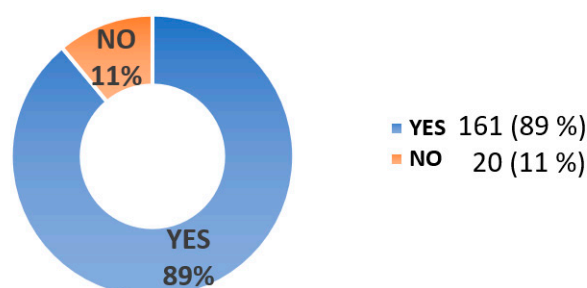


Figure 2. Students who believed that industrial visits improved their learning.

The results shown in Table 4 indicate that it is common for students not to be evaluated for their industrial visits. Moreover, 50% (9) of the professors who visited chemical industries reported that they did not feel that this activity should be included in the final grade of their students.

Table 4. Experience evaluating visits to chemical industries.

	Yes	No
As a student, you have been evaluated on your industrial visits.	76 (42%)	105 (58%)
As a professor, you have evaluated industrial visits.	5 (28%)	13 (72%)

Another interesting result (regarding the opinion of professors about making industrial visits) was that 100% of the professors (18) considered that the industrial visit encourages student participation and learning. All of the professors who made industrial visits in the past felt that these should be included as teaching resources in their classes. However, 22% (4) of these professors reported that this could generate extra work, which could create problems when planning their classes in the future.

Most of the chemistry students and professors made at least one industrial visit (see Table 1). The percentage of students (61%) who had experiences with industrial visits was slightly larger than that of the professors (56%). Although these results suggest that industrial visits are a known and used teaching strategy in chemistry-related careers, it is worth noting that a considerable number of students and professors (approximately 40%) do not use this outside-the-classroom learning strategy. This may reduce the learning opportunities for students who have not had the chance to be involved in industrial visits, which may have had a positive influence in student interests in science applications in real life environments [23,49].

Most chemistry students (83%) and professors (94%) who experienced industrial visits in the past reported having sought this type of learning outside the classroom activity with the motivation to update themselves, and learn more about the subjects taught in class. This suggests that both professors and students seek to engage in industrial visits to develop their knowledge within an environment where they can interact with people highly-trained in current chemical techniques and processes. Figure 1 shows that 89% of students who experienced an industrial visit felt that this activity improved their learning experience. These results were somehow expected based on previous literature suggesting that students usually prefer industrial visits as a learning activity instead of regular lectures in the classroom, or other types of LOTC activities [49,68].

Students who have had experiences with industrial visits learned more about applying the topics taught in their classrooms, and these experiences helped them develop more

critical and participatory attitudes [4,27]. It should be noted that, not just students are motivated to learn from industrial visits, professors also update and enrich their knowledge, from an industrial point of view [2,69,70]. In addition to the academic benefits that students and professors could obtain from industrial visits, the industry could use these industrial visits as a first step for recruiting future chemistry professionals that could show interest and potential for working in the visited industries [71].

Although industrial visits, for chemistry teaching at the college level, turned out to be an activity that piqued the interest of professors and students, it is clear that this learning outside of the classroom activity has not yet been adopted by certain professors who prefer other teaching methods (see Table 1). These professors reported that the main reason for not considering industrial visits as a teaching strategy in their classes was the lack of time, with 86% of them reporting that they did not have the time to plan and make a visit to an industry related to chemistry. This lack of time for organizing an industrial visit on the part of the professor goes hand-in-hand, with the fact that 67% of students reported that they had not made any industrial visits because their chemistry professors had never invited them.

These results suggest that increasing the number of industrial visits by chemistry students requires convincing professors that the time spent on this learning outside of the classroom activity can result in better academic development for their students. Although existing literature mentions that there are various impediments for programming industrial visits [15], these results indicate that lack of time is the biggest obstacle that the professors encounter when thinking about including an industry visit in their chemistry courses. This lack of time should be considered by university administrators in charge of the workload of chemistry professors. If professors do not motivate their students to engage in activities connected with the chemical industry, then students are unlikely to show interest in making industrial visits on their own [72]. Among possible issues that may complicate the planning and organization of industrial visits could be the arranging of transportation from the university to the selected industry. This transportation issue could be a major challenge if there is no sufficient industry around the university, creating possible conflicts for students and professors, who must invest the whole day around an industrial visit—that may negatively affect their academic activities, research projects, or other personal activities [73]. Another challenge for planning industrial visits could be related to safety and confidential regulations that industries may have. The accommodations that any industry must arrange before a visit, to avoid possible safety issues when they allow outside people to enter their building, and perhaps, the will of some other industries to keep their processes and materials a secret, to maintain an edge over their competitors, are important factors that need to be discussed in advance of any possible industrial visit [74]. In the end, planning and conducting industrial visits requires time and work, and most of this workload is normally handled by the professor alone. This workload could be the reason why some professors choose not to include industrial visits in their courses, and universities and chemistry departments could help ameliorate this issue by having administration take charge of planning and coordinating industrial visits.

The results in Table 2 show that the students do not have a clear preference over which semester might be best suited for their first industrial visit. Although the largest group of students (37%) selected the third semester as the best option for industrial visits, the other semesters (first, second, and fourth) also had considerable preferences (no less than 18% for each semester). This indicates that chemistry students may be interested and prepared to take advantage of making industrial visits in any semester from the beginning of their curriculum onwards.

Concerning the professors: 50% of all professors selected the first semester as the best option for inviting their students to industrial visits (see Table 2). This suggests that most professors think about putting their students in touch with the chemistry industry, since the first semester can give them better opportunities to develop their skills and interest in chemistry-related topics. Although the professors believe that industrial visits could have a positive impact on student training, 91% of them showed a preference to conduct

learning outside the classroom activities only once a year, or once every two years. This result must be related to the extra work involved in organizing and attending an industrial visit, which leads professors to think that it is better to organize these visits sporadically instead of once each semester. Concerning the students: 91% of students reported that they would like to have an industrial visit scheduled every semester so that they would have more opportunities to observe how their in-class studies are applied, as well as improve their learning experiences.

All chemistry professors who had made an industrial visit (18) reported having begun their industrial visit with a clear and well-planned objective. Although all professors had a clear goal at the time of the industrial visit, only 78% of students reported that they knew the purpose of their industrial visit before it started. This suggests a lack of clear communication between the professors and students when planning and making an industrial visit, given that 22% of the students attended without understanding the purpose of the activity beforehand. This problem could be mitigated if professors and administrators try to include students in the industrial visit organization and in the decision of which companies they might visit. Then, there would be a space to discuss what may be the most relevant aspects in the visit, and what kind of processes might be observed, in detail, in each industry. Students may feel that arranging visits to certain industries could be a waste of time because they have other interests that are not related to some industries, and visiting an industry in which students are not interested may have a negative effect on their motivation and behavior during the visit [73]. In this sense, the work of planning and performing an industrial visit must be shared between professors, administrators, and students, so that the objectives of the industrial visit are clear, and students can take advantage of the benefits from this learning outside of the classroom activity [3,75]. An additional advantage of including students during the industrial visit organization process is that possible schedule complications with students could be avoided, since students may have other classes or extracurricular activities that may need to be rescheduled with anticipation [73].

Another feature that could improve industrial visits is the evaluation at the end of this activity. It is noteworthy that 58% of the students and 72% of chemistry professors reported never having assessed the process and results of their industrial visits (see Table 4). This lack of an evaluation system can complicate the establishment of an objective, making it difficult to establish whether the goal was met.

If professors could include an evaluation rubric that, from the outset, establishes the learning objective for the industrial visit, then this learning outside of the classroom activity would have a better chance of success, and it might foster student interest in the most relevant activities and processes of the chemical industry they attended. This evaluation would also help professors set realistic objectives oriented to the learning of their students. It would also help professors consider the teaching tools and resources that are available at the location selected for the industrial visit [50]. The lack of assessment of industrial visits may be related to the little interest some professors have shown in including industrial visits as part of the final grade of their chemistry courses. Half of the professors reported not considering the performance and learning of their students during industrial visits as part of the final grade, which may send the wrong message to students that industrial visits are not important, and do not have a well-structured objective.

It is possible that the time and extra work of coming up with objectives and methods of assessment for industrial visits are why 22% of the professors think that including these visits in their course schedules every semester would create long-term problems. This is supported by the observation that, although 100% of these professors recommend including industrial visits as a teaching resource to stimulate meaningful student participation and learning, not all professors are willing to include this activity in their evaluation methods because this requires more work and time than they normally put into planning their chemistry course. An alternative LOtC activity that could have a similar impact than industrial visits could be industrial talks [49]. These industrial talks need to be well-

planned with clear goals and objectives to help professors and students take advantage of the expertise that different professionals could provide during their talks [76]. Similar to the industrial visits, the industrial talks would need extra work and new evaluations, but the workload is less times consuming than planning an industrial visit; with less difficulties to solve by professors and administrators.

At the end, students who complete a chemistry-related major, having some knowledge about the current industry needs, could develop abilities that may help them experience faster incorporation into the industry. This knowledge about industry needs could be facilitated to college students if their universities invite them to get involved with industrial visits, or invite industry professionals that could give them a talk about the current industry processes and technology [74]. Having these types of LOtC activities would help strengthen academic plans and create better learning environments. Students would have better opportunities to develop their skills, helping them feel more motivated to engage in professional activities related to their majors. The positive influence that industrial visits may have on chemistry students' development and motivation could also be a good starting point for solving sustainability problems; as having more prepared chemistry professionals can contribute to regional development, which ultimately would collaborate toward fulfilling the 2030 Agenda for Sustainable Development goals.

7. Conclusions

Results of this study suggest that industrial visits are well accepted by college chemistry students and professors. Students believe that this LOtC activity allows them to improve their knowledge, develop their critical analysis skills, and become more interested in sustainability and chemistry-related topics (see Figure 3). Professors who teach courses in sustainability and areas related to chemistry believe that the industry visits create the right environment for their students to participate more actively in class and engage in professional activities related to their careers (see Figure 3). Despite knowing the aforementioned advantages, these professors feel that scheduling industrial visits in their courses is time-consuming. They prefer that these visits only take place sporadically, with one visit every year or two. If these professors feel that they do not have enough time and support from their university departments to organize and conduct industrial visits (see Figure 3), then these industrial visits are unlikely to take place. Another point that complicates industrial visits is that the professors rarely evaluate this activity, and they usually decide not to include the performance and learning of their students during the industrial visit in the final grade of their courses (see Figure 3). This lack of evaluation may jeopardize the consideration of the industrial visits as teaching methods in sustainability and chemistry courses. Lack of an evaluation system could also complicate the planning and organizing of this activity, since it is not known whether the objective of the visit was well-understood and achieved by the students.

Although chemistry students and their instructors have a positive outlook on industrial visits, there are still a considerable number of students who have never had the opportunity to make one. This situation may detract from the development opportunities of students who are not included in industrial visits. This responsibility relies on chemistry professors and administrators. Administrators in charge of sustainability and chemistry-related programs in universities must strive to create environments where industrial visits are common practice among their professors. For this, administrators must consider the number of courses and the resources they assign to each of their professors each semester, providing professors with enough time to plan and complete all of their academic activities, including visits to chemical industries. If the professors are motivated to make industrial visits, and they are given space in the class calendar to organize and carry these out, then more professors would likely include these LOtC activities, which may ultimately help their students' professional development.

Advantages	Disadvantages
<ul style="list-style-type: none"> • Updating the students and teachers on the technology used by the economic sector. • Improves the interest of the student in chemistry topics. • Develops critical analysis skills in the students. • Encourages class participation. • Involves the student in class planning. • Fosters the connection of students and industry (networking). 	<ul style="list-style-type: none"> • Requires a lot of time to plan and make the visits. • Is a lot of extra work for the professor. • There is no assessment system. • It is difficult to schedule industrial visits every semester. • It is not usually considered a part of the final grade of the student.

Figure 3. The advantages and disadvantages of organizing and conducting visits to chemical industries.

8. Limitations and Future Work

This research was conducted in a city university campus in one of the most important industrial sectors of the western region of Mexico. This city is Guadalajara in the state of Jalisco, in which it provides to this particular university the possibility of having many different options to select industries from a large variety of productive activities. Having different industries close to the university may facilitate planning and conducting industrial visits, and could also help professors choose industries with processes and activities that may fit the syllabus of classes and student interests in a better way. If any university location is different from the context presented in this research, then the university's administrators and professors should consider different issues that may complicate planning and conducting industrial visits, such as transportation and finding the right industry to visit. This issue could be more evident for different cultures and contexts [48].

This survey was a good starting point for documenting how professors and students feel about industrial visits as a LOtC activity, but future versions of this survey can be expanded to collect further and more specific information about the needs for each class. Future data collections could also help chemistry educators understand more about sustainability issues that might be relevant for undergraduate students in sustainability and chemistry majors. To this end, professors may consider visiting industries related to green chemistry or green energy solutions in current processes, which could ultimately help promote student interest in designing sustainable solutions to current regional and global issues.

Author Contributions: All authors contributed equally to this work. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Institutional Review Board (or Ethics Committee) in in the office of the Research Coordination of the Academic Secretary of the University Center for Exact Sciences and Engineering of the University of Guadalajara. and with the principles established in the Code of Ethics of this institution, protocol number: IV/2018/117, session of March 2, 2018 of the General University Council.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data is contained within the article.

Acknowledgments: The authors would like to acknowledge the Writing Lab, Institute for the Future of Education, Tecnológico de Monterrey, Mexico, for the financial and logistical support received to be this article an open access source.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A Questionnaire

Survey translated to English (original questions were in Spanish).

1. Please select your role in the chemistry course you are enrolled in.
(a) Professor (b) Student
2. Have you ever been involved in an industrial visit in college?
(a) Never (b) At least one or more industrial visits
3. If you have been involved in at least one industrial visit in college, what was your main motivation to participate/organize in the industrial visit?
(a) Getting out of the classroom/university
(b) Learning new topics and actualize my knowledge
(c) Relaxing
4. If you have not been involved in an industrial visit in college, what have been your reasons for not participating in/organizing an industrial visit?
(a) Lack of time
(b) These visits are expensive
(c) No one has ever mentioned the possibility of participating in/organizing an industrial visit
5. Which semester would be the best option to participate in/organize an industrial visit?
(a) First semester
(b) Second semester
(c) Third semester
(d) Fourth semester or later
6. How many industrial visits would you like to participate in/organize during the ten semesters of the chemistry major?
(a) One each semester
(b) One every year
(c) Only one during the entire major
7. If you have been involved in at least one industrial visit in college, did you start the industrial visit with a clear goal or objective for doing that industrial visit?
(a) Yes (b) No
8. If you have been involved in at least one industrial visit in college, did you have previous experience working for the industry before this industrial visit? **Just for professors**
(a) Yes (b) No
9. (I) If you have been involved in at least one industrial visit in college, do you consider that participating in industrial visits could facilitate your learning about chemistry topics? **Just for students**
(a) Yes (b) No
(II) Do you consider that the students participating in industrial visits could facilitate their learning about chemistry topics? **Just for professors**
(a) Yes (b) No
10. (I) If you have been involved in at least one industrial visit in college, have you ever been evaluated about the industrial visit? **Just for students**
(a) Yes (b) No

- (II) Have you ever evaluated your students on the industrial visit? **Just for professors**
(a) Yes (b) No
11. (I) By carrying out at least one industrial visit; do you consider that these industrial visits should be evaluated as part of your final grade? **Just for students**
(a) Yes (b) No
- (II) If you have previous experience organizing/realizing at least one industrial visit for your college students, do you consider that these industrial visits should be evaluated as a part of your students' final grades? **Just for professors**
(a) Yes (b) No
12. (I) By doing at least one industrial visit; do you think that these experiences of industrial visits encourage your participation and learning in chemical subjects? **Just for students**
(a) Yes (b) No
- (II) If you have previous experience organizing/realizing at least one industrial visit for your college students, have you ever evaluated your students' performances on any of these industrial visits? **Just for professors**
(a) Yes (b) No
13. If you have previous experience organizing/realizing at least one industrial visit for your college students, do you think that these industrial visit experiences promote student participation and learning of chemical topics? **Just for professors**
(a) Yes (b) No
14. If you have previous experience organizing/realizing at least one industrial visit for your college students, do you think that these industrial visits should be included in the course syllabuses as didactic resources? **Just for professors**
(a) Yes (b) No
15. Do you consider that including industrial visits in your course preparation would generate organizational problems for the professors? **Just for professors**
(a) Yes (b) No
16. Do you consider that conducting industrial visits strengthens the critical and participatory attitude of those who carry them out?
(a) Always (b) Almost always (c) Rarely (d) Never
17. (I) When carrying out an industrial visit, do you deliver a report of the industrial visit? **Just for students**
(a) Always (b) Almost always (c) Rarely (d) Never
- (II) When carrying out an industrial visit, do you ask your students for a report of the industrial visit? **Just for professors**
(a) Always (b) Almost always (c) Rarely (d) Never.

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