

Article

Exploring Chemistry Professors' Methods of Highlighting the Relevancy of Chemistry: Opportunities, Obstacles, and Suggestions to Improve Students' Motivation in Science Classrooms

Anna George ¹, Christian Zowada ², Ingo Eilks ² and Ozcan Gulacar ^{3,*}

¹ Advanced Data Analytics MS Program, University of North Texas, 1155 Union Circle #311070, Denton, TX 76201, USA; Anna.George@unt.edu

² Department of Biology and Chemistry, Institute for Science Education, University of Bremen, 28334 Bremen, Germany; christian.zowada@uni-bremen.de (C.Z.); eilks@uni-bremen.de (I.E.)

³ Department of Chemistry, University of California-Davis, One Shields Avenue, Davis, CA 95616, USA

* Correspondence: ogulacar@ucdavis.edu

Abstract: This study focused on inquiring into undergraduate chemistry professors' efforts in North America to increase student motivation and interest in the subject and the feasibility of methods that connect students to real world applications and societal issues related to chemistry. A survey was distributed to chemistry instructors at post-secondary institutions across the United States and Canada asking about the usage of methods and tools to deliver content aiming at raising students' perception of the relevance of learning chemistry ($N = 124$). The instrument also asked about instructors' perceptions related to assessment, as well as their perception of how their students value the integration of socio-scientific issues into the curriculum. A chi-squared analysis was performed to identify groups of individuals whose responses were disproportionate, compared to the distribution of responses from the sample, in order to identify any unique occurrences. In general, the usage of real-world applications and socio-scientific issues in post-secondary chemistry courses tends to be related to instructors' value of the role of these topics in their courses, comfort level with the topics, and preferred approaches to developing and implementing the course materials.

Keywords: chemistry curriculum; undergraduate; real-world applications; socio-scientific issues



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1. Introduction

Many studies have been conducted to identify and understand the reasons behind undergraduate chemistry students' unsatisfactory performances in the cognitive and affective domains [1]. Among the reasons that have been investigated, a lack of perceived relevance and interest in the topics [2], poor motivation [3], lack of prior success [4], and low self-efficacy [5] have been posited often as common causes. In order to understand the nature of these challenges, chemistry instructors' curricula and teaching method choices must be investigated. Many chemistry instructors aim to cover every aspect of foundational knowledge, but this often results in instruction that does not include many of the connections between chemistry topics and issues relevant to real-world applications [6,7]. Among those who aim to connect concepts to ideas beyond the classroom, many simply introduce the industrial applications and daily uses. Although these examples help some students relate chemistry to their daily lives, they are far from truly changing students', especially non-chemistry and non-science majors', opinion on the necessity of learning chemistry and stimulating their interest in the subject matter. There are studies revealing the potential for new and uncommon activities and topics to excite students with the aim of increasing student engagement in learning chemistry [8,9]. These novel activities do not focus on content knowledge such as types of crystalline solids, rather, they connect students with the broader picture of the practical implication of these concepts. For instance,

when discussing isotopes, it is important to connect students to the greater implications of isotope stability by discussing the importance of phosphate sustainability for the future of agriculture. From our perspective, as well as the perspective of many others [10–13], teaching chemistry is also about including opportunities for students to visualize the bigger picture and practical applications of these concepts in local and global economies, society, and the environment [14]. Implementing Science, Technology, Society, and Environment (STSE) approaches or the integration of socio-scientific issues into teaching can provide students the opportunity to connect chemistry to society and their daily life, and, in turn, increase student motivation and interest in the subject [13].

The extant research, however, has not adequately explored to what extent professors in North America have utilized these findings and what methods they have incorporated into their teaching to address students' lack of interest in science topics [2]. Although chemistry has endless connections to the world we live in and a considerable potential in inspiring students, it has mainly been taught in a way that poorly connects the content to students' individual lives, future careers, or societies [15,16]. Chemistry educators are not doing an effective job at integrating a broader picture or at portraying a more holistic view while teaching chemistry [13]. In order to change the idea of teaching towards a more holistic view, the first step is to realize most students in college chemistry courses do not plan to have a career in chemistry fields. Mahaffy [7] (p. 7) points out this implicit belief paramount in chemistry classrooms, "overemphasis is often placed on providing all of the foundational pieces for the few students who major in chemistry, rather than for the majority of students who will pursue careers in health professions, engineering, or other areas". Once this fact is understood, the educators should feel more inclined to enrich chemistry curricula rather than covering the traditional content, and incorporate more diverse issues such as global food scarcity, the need for more efficient and productive ways for agriculture, or the role of chemistry in polluting water resources around the world as suggested by Hodson [17].

While these approaches seem to be appealing to many concerned chemistry educators, and literature [9,18] provides evidence on their effectiveness to encourage professors to consider fundamental changes in their teaching philosophies and modify their curricula, the number of professors who utilize these effective methods is not that high. When investigated in-depth, it would be better understood why teaching methods have not been updated or reformed as much as things have evolved around us in centuries. Change is difficult, and it takes a long time, especially when it involves human beings. In 1985, the AAAS committee came together to address the increasing concerns around the low level of the public's science literacy in the United States. After extensive meetings, they published several reports and initiated vital projects including the Project 2061. Although the Halley's Comet was the apparent reason for the them to call "Science for All Americans" project as Project 2061 since its next perihelion is in 2061, the main goal was to highlight the difficulty of seeing the desired changes and achieving this precious goal in a short amount of time [19]. Many reports [20–23] analyzing reform efforts in STEM education acknowledge that change does not happen quickly, and even educators show some resistance before accepting new ideas and embracing them into their lives or jobs. While there are many challenges cited in the literature, it does not mean that it is impossible to accomplish these important goals. Talanquer and Pollard [24] share their journey and challenges associated with their plans of changing the entire General Chemistry Curriculum at their institution. They acknowledge that after overcoming many obstacles, they were able to successfully adopt a completely new approach and curriculum, collectively called Chemical Thinking, to better equip their students to deal with the 21st century problems more successfully. Mahaffy, et al. [25], Mahaffy [26], also provide a recipe to connect chemistry courses with a broader view on science and revamp chemistry teaching successfully by integrating systems thinking.

This study was designed to gain insight into undergraduate chemistry professors' common challenges and views on how to increase student motivation and interest in chemistry as well as their beliefs about the feasibility of exposing students to real world

applications and socio-scientific issues related to chemistry. In addition, the goal of the study was to determine how much the professors were able to incorporate methods and curricula suggested by the educational researchers and cognitive scientists. The respondents were asked to share the ways they prefer to customize their topics of discussion in their classrooms to increase student engagement.

2. Method and Sample

2.1. Instrument

A survey instrument was developed to document the efforts of chemistry professors who teach at higher education institutions across the United States and Canada to increase student motivation and interest in the subject and the feasibility of the methods exposing students to real world applications of chemistry and socio-scientific issues. The survey instrument was developed in Qualtrics, based upon input from chemistry students and instructors for face validity, and its link was distributed on listservs (e.g., CER Listserv) whose members are known to be instructors of chemistry at post-secondary institutions. The survey collected information on the type of institutions (e.g., community college, doctoral granting institutions) where the participants work, the specific courses taught, if they use frequently mentioned methods (e.g., demonstration, animations/simulations) in their classrooms, and their beliefs about the effectiveness of these efforts in motivating students to learn more chemistry, using both Likert-scales and open-ended questions.

The survey instrument consists of four specific areas related to instructors' efforts to integrate real world applications of chemistry and socio-scientific issues into their courses, namely (i) methods used by instructors to show chemistry's relevance for their students; (ii) instructors' perceptions of using commonly cited methods and topics that are known to be effective in increasing students' motivation; (iii) assessment efforts to incorporate such topics; and (iv) challenges that may prevent implementation of those methods and topics, such as socio-scientific issues, into their teaching. Items collected information regarding preferred methods and materials utilized for instruction as instructor perceptions of how well these methods are perceived by students from the instructors' point of view. Among all items regarding methods and materials utilized, the survey specifically requested information regarding the use of socio-scientific issues based on a definition provided by Sadler, et al. [27]. It was clearly mentioned that for an issue to be considered as a socio-scientific issue, it needs to meet a set of criteria such being authentic, relevant, open-ended, controversial, complex, and involving both science and society.

2.2. Participants

An invitation to participate in the study was advertised to chemical educators in which 124 chemistry professors across the United States and Canada with a wide range of background and teaching experiences accepted the invitation and completed the survey in May 2018 using a convenience sampling approach. The largest portion of respondents represented doctoral granting institutions (55.44%), followed by community colleges (24.19%), masters granting institutions (14.11%), primarily undergraduate institutions (PUIs) (8.7%), and institutions classified as "other" (4.3%). Nineteen of the respondents (15%) did not indicate their institution type. While the most common course taught in this sample set was General Chemistry, many participants also had teaching experience in Inorganic, Organic, Physical, and Biochemistry as well. Other less frequently mentioned courses included Physical Science, Analytical, Environmental, and Calculus-based General Chemistry.

2.3. Analysis

For the purposes of analysis, items that were selected were coded as 1, and the unselected items were coded as 0. Unanswered questions or portions of questions were left blank and excluded from the analysis. All data were analyzed using IBM SPSS 23 and Excel for this study to identify any differences between different types of groupings for chemistry instructors. In order to evaluate the usage of various techniques, chi-squared analysis

was used to test whether the proportion of instructors providing specific responses was significantly higher or lower than in the whole sample. Split-group multivariate analysis was performed to verify the homogeneity of the sample. A random dichotomous indicator variable was introduced, and each topic group (methods used to make chemistry relevant, methods used to deliver material, obstacles to integrating SSIs (Socio-scientific Issues) into courses, etc.) utilized in the chi-squared analysis was investigated to determine if there was a significant difference between the random subgroups. Hotelling's Trace was employed due to the segmented nominal structure of the data. Tests for each group were determined not to be significant (p values ranging from 0.510 to 0.931) at the 0.05 level, indicating that the subgroupings are not distinct in nature, thus providing additional support for internal consistency.

3. Results and Discussion

3.1. Methods Utilized to Raise Students' Perceptions of the Relevance of Learning Chemistry

Of the total sample, 88 respondents provided responses indicating different methods for making chemistry interesting and raising the perception of relevance for students. The most commonly suggested methods among these 88 respondents were sharing real-life stories involving chemical concepts (77.6%), and introducing applications of chemical principles (80.7%), followed by discussions of different uses for chemicals (62.5%) as suggested by Childs, et al. [28]. Only half of the participants suggested integrating SSIs (49.4%) as suggested by Sadler, Barab and Scott [27] (Figure 1). Specific emphasis towards eco-reflexive and sustainability-oriented innovations was not expressed by a larger part of the participants as suggested by Sjöström, et al. [29].

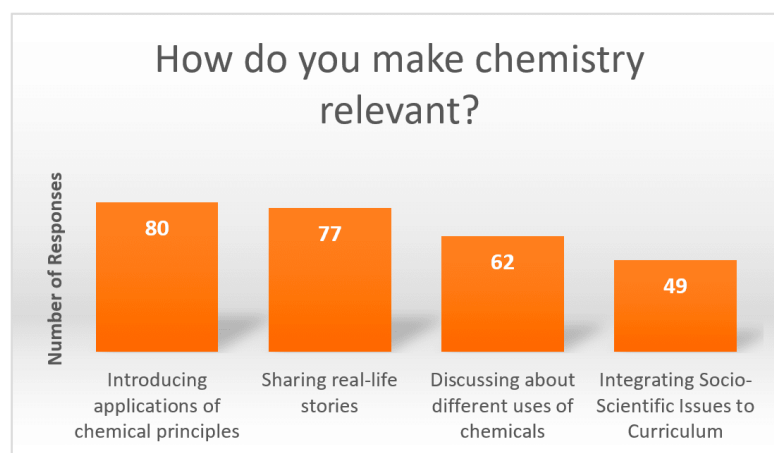


Figure 1. Methods suggested to raise students' interest and perception of relevance of learning chemistry.

Of the total sample, 77 of the respondents provided information about the methods they utilize to deliver corresponding information in their classes. Lecturing was the most common method chosen by instructors (66 out of 77; 85.7%). Additionally, the combinations of tools to present material were evaluated, with some combinations occurring as many as 33 out of 77 (42.9%). Of those who indicated the use of lectures, 51 out of 66 instructors (77%) indicated the use of lecturing in combination with other methods. The most common pairing with lecturing was the use of videos (25.4%) (Figure 2). The use of interactive digital learning materials, as, e.g., suggested by Zowada, Gulacar and Eilks [9], were not mentioned.

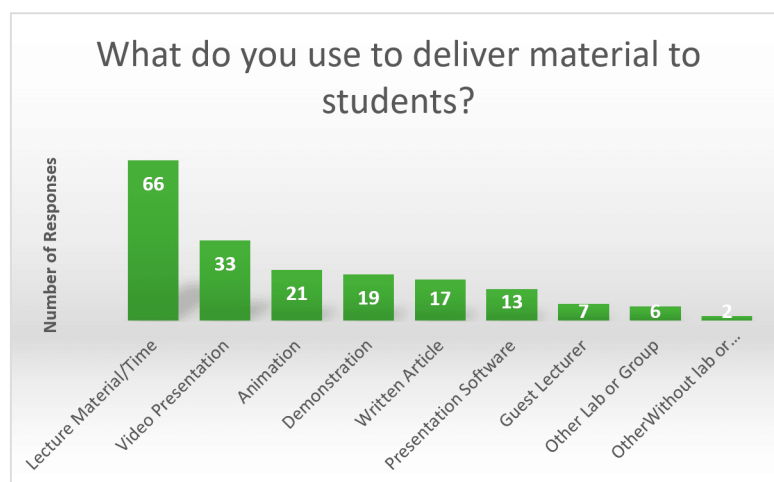


Figure 2. Methods to deliver information in chemistry courses.

Demographic information provided by instructors, including the type of institution, the courses taught by respondents, and their teaching experience did not produce any significant differences at the 0.05 level for the choices provided. However, there were three pairings between methods that instructors utilize to make chemistry be perceived as relevant, and tools utilized to deliver course materials to students appeared to be significant. The first significant association ($\chi^2(1, N = 77) = 9.625, p = 0.002$) was found for whether instructors reported explicitly integrating socio-scientific issues into their curriculum in relation to utilizing animations in class. Instructors who reported that they commonly use animation to present content did less select that they integrate socio-scientific issues into their curriculum disproportionately compared to all responses. For these instructors, this may result from a preference for emphasizing content at the particulate level as opposed to relating chemical concepts to daily life and societal issues. There was also a significant association ($\chi^2(1, N = 77) = 4.627, p = 0.031$) among instructors who indicated utilizing applications of chemical principles to make chemistry interesting and relevant for students with utilizing guest lecturers to deliver content to students. Instructors who indicated that they commonly use guest lecturers to present topics in their classes did not indicate that they introduced applications of chemical principles in their classes disproportionately compared to all responses provided for this question. Finally, a significant association ($\chi^2(1, N = 77) = 7.889, p = 0.05$) was identified between the utilization of sharing real-life stories involving chemical concepts, as, e.g., suggested by Childs et al. [28], and instructors who indicated laboratory exercises as an “other” category as a method for delivering course materials to students. Instructors who indicated that they commonly use laboratory activities to present topics in their classes did not indicate that they share real-life stories involving chemical concepts in their classes disproportionately compared to all responses provided for this question.

3.2. Perception of Instructors

When being asked whether students would be motivated to learn topics related to socio-scientific issues if students were aware that the topics would not be included on exams, of the 40 respondents who answered this question, 47.5% indicated “might or might not” and 37.5% indicated “probably yes” and “definitely yes”. However, only about one third of the participants answered this question (Table 1).

Table 1. The distribution of responses for the question, “Do you think your students will be motivated to learn these topics if these topics do not appear on the test?” by institution type.

		Community College	PUI	Masters Granting Institution	Doctoral Granting Institution	Other Institution Type	No Response	Frequency	Percent of Responses to This Question
Do you think your students will be motivated to learn these topics if these topics do not appear on the test?	Definitely not	0	0	1	1	1	0	3	7.5
	Probably not	1	0	0	2	0	0	3	7.5
	Might or might not	7	3	4	5	0	0	19	47.5
	Probably yes	2	0	2	9	0	0	13	32.5
	Definitely yes	0	0	1	1	0	0	2	5.00
	Did not answer this question	4	5	6	37	3	19	84	

Participants were also asked to approximate the percentage of the material they teach was comprised of socio-scientific issues. Of the participants, 76 participants responded to this question. A large portion of respondents indicated that they used less than 5% (48.7%, 37) or 5–25% (34.2%, 26) of teaching materials related to socio-scientific issues, with 25–50% and greater than 50% having 2 responses each.

Some of the respondents (9, 11.8%) indicated that the proportion of the material including socio-scientific issues varied, due to more than one type of method used. Respondents who indicated as such were also asked to explain how the proportion changed. Responses indicated that the proportion tended to depend on the topics for various courses as well as the audience of the course (e.g., Nursing Chemistry) (Table 2).

Table 2. Percentage of material incorporating socio-scientific issues.

		Frequency	Percent of Responses to This Question
About what percent of the material you are teaching is made up of these topics (e.g., socio-scientific issues)?	Less than 5%	37	48.7
	5–25%	26	34.2
	25–50%	2	2.6
	Greater than 50%	2	2.6
	Percentages change if more than one type is used	9	11.8
	Did not answer this question	48	

Even though the understanding of what constitutes relevance in science education might vary [16], of the comparisons between the responses for how respondents try to make chemistry interesting and relevant for students and the approximated percentage of course material comprised of socio-scientific issues, the relationship between the percentage of class time and those who indicated that they specifically utilize socio-scientific issues to make chemistry interesting and relevant for students resulted in a significant association ($\chi^2(4, N = 76) = 15.201, p = 0.004$). Respondents who indicated that they utilize less than 5% of class time on socio-scientific issues did not indicate that they integrate socio-scientific issues to make chemistry relevant disproportionately more and that they do integrate socio-scientific issues disproportionately less than among the whole sample. This is a logical result because it is indicating that a large portion of respondents who do not integrate socio-scientific issues in their curriculum dedicate less than 5% of course materials to these issues.

3.3. Nature of Assessment vs. Reform Efforts

Of the 87 respondents who answered the question if socio-scientific issues are present in exams, 40 of them indicated that they do not, while 47 indicated that they do. Of the 39 respondents who answered both questions about instructor perception of student motivation, all respondents indicated that questions related to socio-scientific issues were included on exams. All 40 respondents who indicated that these topics are not included on exams did not answer the question asking about their perception of student motivation to

study these topics if they are not tested on exams. As such, the distribution of responses remained constant for all the respondents who selected “no” for including the topics and examples on exams, and therefore a chi squared evaluation was not considered to be useful (Table 3).

Table 3. Perceived student motivation by inclusion of socio-scientific issues on exams.

		Do You Ask Questions Related to These Topics and Examples on Exams?			
		No	Yes	Did Not Answer This Question	Total
Do you think your students will be motivated to learn these topics if these topics did not appear on the test?	Definitely not	0	6	0	6
	Probably not	0	3	0	3
	Might or might not	0	17	0	17
	Probably yes	0	11	0	11
	Definitely yes	0	2	0	2
	Did not answer this question	40	8	37	85
	Total	40	47	37	124

The comparison between the responses for the estimated percentage of material made up of socio-scientific issues and if exam questions related to these topics are used resulted in a significant association ($\chi^2(4, N = 76) = 11.762, p = 0.019$). Respondents who reported utilizing less than 5% of material with socio-scientific issues indicated that they asked questions related to these questions disproportionately more frequently, and that they do not ask related questions disproportionately less frequently than in the whole sample (Table 4).

Table 4. Percentage of course materials by inclusion of socio-scientific issues on exams.

		Do You Ask Questions Related to These Topics and Examples on Exams?			
		No	Yes	Did Not Answer This Question	Total
About what percent of the material you are teaching is made up of these topics (e.g., socio-scientific issues)?	Less than 5%	25	12	0	37
	5–25%	9	17	0	26
	25–50%	1	1	0	2
	Greater than 50%	0	2	0	2
	Percentages change if more than one type is used	2	7	0	9
	Did not answer this question	3	8	37	48
	Total	40	47	37	124

3.4. The Challenges and Obstacles for Instructors

Respondents selected a variety of challenges to implementing SSIs in their curricula, including several combinations, like class size (61), topics in the curriculum (27), depth of the example being beyond the scope of the course (24), lack of adequate time (16), and comfort with the application (3). Some of the “other” obstacles provided included lack of desire to incorporate socio-scientific issues into lessons, avoidance of controversial topics, comments from students wanting material pertaining only to topics relevant for the exam (such as the MCAT), and the perception that students would not be interested (Figure 3).



Figure 3. Perceived obstacles.

Instructors who indicated comfort with the application as an obstacle to the integration of socio-scientific issues into their classes resulted in a significant association with not utilizing real-life stories involving chemical concepts ($\chi^2 (1, N = 77) = 7.960, p = 0.005$). The number of respondents who indicated their comfort level as an obstacle did not select sharing real-life stories involving chemical concepts in their classes disproportionately more frequently than expected when compared to all responses provided for this question (Table 5). Individuals who are uncomfortable integrating these issues into their courses would also not utilize real-life stories involving chemical concepts. Some of the comments provided by respondents regarding their comfort level being a barrier to implementation included “Being able to generate enough synergy with lecture content and learning goals without giving incorrect data”, “Many times it does not help the flow of content delivery”, and “Not knowing myself what more relevant applications might be.”

Table 5. Chi-square results for comfort with application as an obstacle to the integration of SSIs and sharing real-life stories.

		Relevance—Sharing Real-Life Stories Involving Chemical Concepts		Total	
		No	Yes		
Obstacle— Comfort with the application	No	Count	8	66	74
		Expected Count	9.6	64.4	74.0
	Yes	Count	2	1	3
		Expected Count	0.4	2.6	3.0
Total		Count	10	67	77
		Expected Count	10.0	67.0	77.0

The comparison between the topics in the curriculum not being conducive to incorporating socio-scientific issues into course materials and respondents who did not incorporate socio-scientific issues to make chemistry relevant and interesting for students resulted in a significant association ($\chi^2 (1, N = 77) = 4.867, p = 0.027$). Instructors who indicated that their curricula did not have topics that were suitable for utilization of socio-scientific issues in their classes did not indicate that they integrate socio-scientific issues into the curriculum disproportionately less compared to the values based on all responses provided for this question (Table 6).

Table 6. Chi-square results for the selected course topics being incongruent with SSIs as an obstacle for SSIs into course materials with using SSIs.

			Relevance—Integrating Socio-Scientific Issues to Curriculum		Total
			No	Yes	
Obstacle— Curriculum—does not fit set topics	No	Count	26	24	50
		Expected Count	21.4	28.6	50.0
	Yes	Count	7	20	27
		Expected Count	11.6	15.4	27.0
Total		Count	33	44	77
		Expected Count	33.0	44.0	77.0

While it seems logical that the group of instructors who indicated that they perceived that the topics of their courses did not easily lend themselves to utilizing SSIs and did not indicate using SSIs to help make their course relevant for their students was much larger than expected based on the chi square analysis, further investigation was completed to determine the characteristics of the respondents in this group. Two of these instructors indicated a significant background in working in the chemical industry prior to becoming an instructor. All of these instructors had experience teaching general chemistry ranging from less than 5 to more than 25 times, and only 2 had indicated any experience teaching at least one section of chemistry for non-science majors. Of the topics that these instructors would like to see integrated into their subject, six of them indicated that they would like to see environmental issues integrated into the curriculum.

4. Limitations

This study is based on the analysis of the responses provided on a survey from 124 participants. It is, however, not clear how representative the sample in this study is, and there can be only speculation about what the views of those participants were when not answering some of the questions. Aside from that, data used for this study was self-reported and therefore is limited by the interpretations imposed by the respondents for the various categories and terms used in the survey. For example, all participants were provided with the definition of SSIs as outlined by Sadler, Barab and Scott [27], but participants' conceptualization of SSIs was not evaluated. Therefore, there may be a margin of error here due to differences in interpretation of this terminology. For example, one of the respondents who indicated that the percentage of course material utilizing socio-scientific issues indicated in the description of how the percentage changed a preference for utilizing culturally-oriented examples as opposed to societal-oriented issues. This person may not have referred to the definition provided in the survey. Additionally, when asked about methods used to make the learning of chemistry relevant, some participants selected "other" and provided descriptions that were classified by the researchers as "applications of chemical principles". Nevertheless, the survey may provide some tendencies that can inform future curriculum development in undergraduate chemistry teaching.

5. Conclusions

For many students, it is not clear why they should learn chemistry [2]. They often do not see the relevance of chemical knowledge to their lives and future. Most chemistry instructors at the undergraduate level seem to be aware that they need to contextualize the learning of chemistry facts and concepts in a meaningful way [2]. This study revealed that the most preferred strategies are introducing applications of chemical principles in different contexts with limited details and telling real-life stories involving chemical concepts [28]. The tools suggested by the instructors in this study range from audio/video presentations, animations, and live demonstrations to written articles, lecture material, and guest lecturers, with lectures being utilized by most of the respondents. Applications of chemical principles and sharing real-life stories are applied far more frequently than discussing the different

uses of chemicals or integrating SSIs into undergraduate chemistry teaching. The reasons for instructor perceptions and preferences might be varied. Aside from typical obstacles, like time constraints or incongruent matches with the given standards, there are clear reasons for different approaches themselves as well. Sharing a real-life story and referring to an application of chemistry are strategies that can be done in a short timeframe, as an add-on to theory learning, and neither strategy includes the potential for controversial discussions in theoretically complex questions. The varying uses of chemicals and authentic, complex, and controversial socio-scientific issues derive much more from the common ground of traditional chemistry teaching [30]. Referring to issues such as the use of chemicals and their impact on the environment or responses to challenges, like climate change, the overabundant use of plastics or the chemicalization of the environment by novel entities within the context of an introductory course poses several challenges for instructors [31]. This level of discussion would require more time, has the risk of introducing contradicting points of view, and requires a systems thinking perspective [32] in chemistry education that is not well represented in traditional chemistry curricula and corresponding teaching media. Nevertheless, about half of the participants that answered the corresponding question (approximately one third of the whole sample) suggest that socio-scientific issues are included in the undergraduate chemistry curricula at least to a certain extent. Further research might reveal the topics selected and strategies used in chemistry courses to address the inherent complexity of authentic and controversial socio-scientific issues for making chemistry learning more relevant in the eyes of the students. For example, Gulacar et al. [18] determined that dedicating a single discussion session to the exploration of a socio-scientific issue, phosphate sustainability, was sufficient to improve 760 college students' self-efficacy and motivation in many categories. In another study, Zowada, Gulacar, and Eilks [9] also identified positive changes in students' perception of chemistry and its role in our society when they were charged with a discussion around hydraulic fracturing, another hot socio-scientific topic capturing the public's attention.

The inclusion of socio-scientific issues is not limited to the concern of increasing motivation or raising the perception of relevance of chemistry learning among students [30]. Integrating these topics into general courses where the focus in teaching the fundamentals, as opposed to a special topics course, is challenging [31], and is a decision all chemistry educators need to evaluate as they determine how chemistry education will keep up with the modern challenges global society is facing today. The recently published Global Chemicals Outlook II (GCO II) by the United Nations Environmental Program [33] clearly outlines the need to teach about the role of chemistry and the impact it has on these challenges. Out of 17 Sustainable Development Goals issued by the United Nations [34], at least 10 are directly linked to chemistry [33]. This can form a new approach to re-aligning the chemistry curriculum [35,36]. In this century, chemists and chemistry educators are challenged as well as required to address the needs for environmental protection, climate action, and responsible use of resources, in addition to fighting poverty and stopping hunger [33]. Many of the related challenges are controversial in nature. Thus, they can be considered relevant to educate responsible citizens and to introduce chemistry approaches in the means of eco-reflexive education [29] and systems thinking [32]. This task is also clearly suggested in the GCO II for chemistry education in high schools, higher education, and lifelong learning [33].

One of the biggest obstacles in integrating socio-scientific issues and systems thinking approaches to chemistry education could be the traditional practices of assessment. As long as assessment is not changing to include aspects of the applications of chemistry, its effects on the society and the environment, and potential answers to sustainability challenges it will stay difficult to implement corresponding curricula on a broad base. Or, changes in the curricula will stay restricted to more or less isolated actions of individual chemistry educators being convinced by the motivating character of SSIs and their potential to contribute to a broader set of educational goals [37]. Another obstacle mentioned in

the literature, for example, in the case of sustainability-oriented SSIs, is a lack of teaching materials and good practice examples [38].

Further investigation could be made to posit as to whether the lack of implementation of SSIs is related to the types of supplemental information provided to instructors from textbook companies or from personal experiences prior to becoming instructors. It is likely that instructors who have experience working in the chemical industry have additional experiences that they can bring into the classroom to enrich their students' learning. Future studies need to evaluate the resources available to instructors specifically pertaining to the implementation of SSIs in chemistry courses. Such research may include a comparison of implementation of SSIs at the secondary and higher education levels to see whether undergraduate teaching may benefit from experiences gained at high schools.

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