Charles University – Faculty of Education

Department of Chemistry and Chemistry Education

PROJECT-BASED EDUCATION AND OTHER ACTIVATING STRATEGIES IN SCIENCE EDUCATION XXI.

Conference proceedings

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(Eds.)

2nd– 3rd November 2023

Prague

The conference is held under patronage of dean of the Faculty of Education, Charles University prof. PaedDr. Michal Nedělka, Dr.

ISSN 2695-0626

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Green chemistry - practical solutions in the chemistry laboratory

Małgorzata Nodzyńska-Moroń

Abstract

Laboratory classes are an important element of chemical education. We explored the possibility of replacing traditional school experiments with other experimentation techniques such as the use of microscale and droplet analysis, microwave oven, microscope, and online laboratories. 44 university students participated in the research. They carried out traditional and modified experiments and assessed them in terms of safety, environmental nuisance, and satisfaction. Students reported enjoying the new techniques, but after 8 years of learning traditional chemistry, they did not perceive the harmful effects of traditional experiences. Therefore, they did not agree with the need to replace traditional experiences with more ecological ones. The obtained results show that chemistry students and future teachers do not recognize the role of green chemistry and do not consider it necessary to redesign chemical experiments to make them more environmentally friendly.

Key words

Green chemistry; ecology; laboratory classes

INTRODUCTION

It's believed that there are many reasons why chemistry is one of the essential subjects in science education:

1. Allows to understand the world - it helps to understand how different substances and processes work within our environment. This allows to understand how different chemical reactions occur and why.

2. Has many practical applications - it is regularly applied in many industrial processes that influence our daily lives; thanks to it, we can create new medicines, building materials, cosmetics, as well as food products; understanding chemistry also allows us to better understand technologies such as solar energy and nanotechnology.

3. Affects our health and safety - knowledge of chemistry is essential to understanding the effects of chemicals on human health and the environment; using this knowledge we can make informed decisions regarding the substances with which we come into contact and minimize the risk of their negative impact.

4. Affect our career and personal development - chemistry can be the basis of many professions, such as chemist, pharmacist, or engineer; having chemical knowledge can open many career opportunities. In addition, learning chemistry develops analytical skills, logical thinking, and problem-solving abilities.

Yet, despite all those aforementioned benefits, chemistry education at all levels can be environmentally disruptive. Therefore, when teaching chemistry, it is essential to use teaching methods and techniques that cause the least amount of harm to the environment.

THEORETICAL BACKGROUND

The application of the green chemistry approach to chemistry education is essential. The concept of "green chemistry", involving both the design and the implementation of technological experiments and processes to limit the use and the production of harmful chemicals, came about at the end of the 20th century. In 1991, Anastas introduced the term "green chemistry" ('Father of green chemistry' Paul Anastas to head EPA research). Together with Warner they defined green chemistry as “the research, development and implementation of products and processes to reduce or eliminate the use and production of dangerous” (Anastas & Warner, 1998). This concept is based on the 12 principles green chemistry and 12 principles of green technology (Winterton, 2001). Although the principles of green chemistry are talked about a lot in the context of industry, the situation is different in the context of school education. There is a lack of theoretical and practical frameworks showing how to apply the ideas of green chemistry to education. However, teachers must put in a lot of work on their own to adapt and translate green chemistry from an industrial or production perspective to a more suitable one for younger students (Nahlik et al., 2023).

Many scientists are conducting research on this topic and articles on introduction of the principles of green chemistry into education have been appearing since 2001. The literature review shows that they can be divided into two trends. Some researchers focus mainly on detailed solutions enabling the transformation of (single) school experiments into experiments consistent with the principles of green chemistry. However, there are also publications whose main goal is to survey current and future chemistry teachers regarding their knowledge and attitudes toward green chemistry. The first type of research will include, for example, the research described in the article by Hempelmann and Caltun (2018) describes two examples: Omega-3 fatty acids from local plants (instead of fish oil) and ionic liquids as recyclable, tenable solvents for dissolving and processing biomass in the form of wood and its ingredients to create alternative processes that are safer and free from waste and additives. Furthermore, the article by Linkwitz, Belova and Eilks (2021) describes a lesson plan about a compound contained in cosmetic products, namely L-carvone. One example the second type research is a study conducted by Basheer et al. (2023), who examined 271 science teachers in Israel. Among the

participants, there were teachers who were already in the profession as well as ones preparing for it. As part of their research authors surveyed the participants in terms of their level of awareness about green chemistry and sustainable development, as well as their approach to education as ecological. The results showed that teachers' awareness of sustainability and green chemistry was generally low, although their views on environmental education were generally positive. Furthermore, science teachers, who were already teaching, were found to have more knowledge about green chemistry and sustainability than pre-service science teachers. Teachers with over 10 years of experience had the greatest knowledge. In another research, Karpudewan and Kulandaisamy (2018) designed and examined green chemistry experiments for their applicability to high school chemistry teaching. As a part of this research, 70 secondary school teachers stated that green chemistry experiments were consistent with the current curriculum, feasible to implement, encouraged inquiry, safe, and relevant. These results suggest that green chemistry can be integrated into mainstream chemistry education. In another study, the results obtained by Karpudewan et al. (2012) indicated that the group of students (future teachers) performing "green experiments" was more internally motivated than the group performing traditional experiments. These changes were mainly due to the personal satisfaction participants derived from engaging in pro-environmental behaviours.

Considering the above, it was decided to develop global solutions that will enable the transformation of traditional school chemical experiments into an eco-friendly version. The following assumptions were made. Food reagents and everyday materials (e.g. instead of metal shavings, nails made of various metals were used) were used in place of traditional chemical reagents. Efforts were made to ensure that the reaction products could be used in other experiments or that they were safe for the environment. Classic microscale experiments and droplet analysis were used as typical small-scale chemistry (SSC) experiments, supplemented with microscopy experiments. Although the microscope is commonly associated with research in biology, it also provides great service in teaching chemistry. The basic use of a microscope in chemistry is to observe the shape of crystals of chemical compounds, i.e. its use in crystallography. Nowadays, however, it is increasingly used as one of the microscale methods. In this case, the course of the chemical reaction (and the formation of crystals) is observed directly under a microscope, on a glass slide (with a so-called teardrop). The most common usage of this method is in reactions where the displacement of metals from their salts occurs (Pikuzińska, Cieśla & Nodzyńska, 2014). Nowadays, it is not uncommon to use a microscope that is connected to a computer or a phone with a microscope application.

Since the possibility of using microwaves in experiments was first mentioned in 1986 (Gedye et al., 1986), several thousand articles have been written describing their use in the synthesis of substances (The Web of Science query "microwave" & "chemistry" yields 11,621 publications). It plays an

important role due to high efficiency and selectivity, easy separation, purification of products and economy. Direct microwave heating significantly shortens the chemical reaction time and reduces side reactions. A microwave oven was also used. The use of microwaves allows, among other things, the use of diluted reagents (e.g. in the synthesis of esters, we can use dilute sulfuric acid instead of concentrated sulfuric acid) and allows the substances to be heated for a shorter time (e.g. in the dehydration of copper(II)sulphate decahydrate or in the thermal decomposition of ammonium chromate(VII)). The advantages of using microwave ovens in school education in the field of green chemistry have been widely described by Čermák et al. (2010), Kolář, Nodzyńska and Cieśla (2015) or Šulcová and Böhmová (2007a; 2007b). Online labs or simulations have replaced some of the experiments. In place of running water, a refrigerator or ice was used for cooling.

RESEARCH & METHODOLOGY

Students subjected the experiments developed in this way to practical evaluation in the first year of master's studies (future teachers of chemistry and biology). The research aimed to evaluate whether replacing traditional experiments with those that consider the principles of sustainable development (e.g. green chemistry) will affect the students' sense of security and whether they will notice how changing the technique of conducting experiments affects the environment. And whether they will feel safer conducting these modified experiments. It was assumed that after 3 years of laboratory classes in undergraduate studies, students are aware of their users and are aware of the environmental hazards posed by some of the experiments.

The research involved 44 students from master's studies in the field of Teaching Biology and Chemistry. These students had a bachelor's degree in biology or chemistry where they previously had traditional laboratory classes in general, analytical, inorganic, and organic chemistry. As part of the "Designing Chemical Experiments" course, they got acquainted with various techniques for conducting chemical experiments so that they would be more aware of the ecological impacts of experiments and consider the principles of sustainable development (e.g. green chemistry). Students independently designed and performed experiments using a microscale (including droplet analysis), a microwave oven, a microscope and online laboratories or simulations.

The research aimed to check whether there is a real possibility of replacing school chemical experiments with more ecological alternatives. That is, whether new versions of experiments are safer, less burdensome to the environment and whether their performance brings greater satisfaction to students. And what students - future chemistry teachers - think about it.

A questionnaire was used for the research. The main measurement strategy used in this survey questionnaire was the Likert scale. It allows us to obtain knowledge about the degree of acceptance

of views and is often used to measure attitudes towards specific events, objects or problems. In total, students were asked 35 questions in the study. 33 of them were closed questions, where a 5-point Likert scale was used, as well as one closed question with YES/NO answer, and one open-ended question.

Because during scientific research, the question always arises whether the results obtained are statistically significant. The obtained results were processed in the Jamovi statistical program.

RESULTS

For many of the variables, the distribution was not normal (see Tab. 1). But it is difficult to expect a normal distribution, e.g. in questions about age (when these are students of the same age), gender (in Poland, there is a clear predominance of women at university). It is also difficult to expect diverse answers (consistent with a normal distribution) in questions regarding their everyday laboratory practice (answers to questions: 1-8, 11-12, 21, 26-29, 31-34). But in a situation where the question concerned new problems that did not appear in chemistry classes in which they had previously participated (questions 9, 10, 13, 14, 15, 16, 17, 18, 19, 20, 22, 23, 24, 25, 30) the distribution of answers was consistent with the normal distribution. It can therefore be assumed that the obtained results are statistically significant.

The first part of the research concerned traditional laboratories. The first two questions concerned the students' belief in the need to perform experiments in chemistry classes and their sense of safety in such classes (Tab.2). Most students believe that experiments are an essential element of chemical education (74.1%) and feel safe during this type of classes (79.6%).

Furthermore, the answers to questions about self-conducting experiments, using a burner or using concentrated solutions show quite a high self-confidence in students (Tab. 1.). 56.8% of students are not afraid of using the burner on their own and 54.5% are not afraid of experimenting and using concentrated solutions on their own. It can be assumed that students are confident users of the laboratory. The following questions checked whether students were aware of the negative impact of the chemistry laboratory classes on the environment and the environmental hazards of some of the experiments (Tab. 2). It turns out that most of the surveyed students disagreed with the statements that too many reagents are used, too much water is used, too much electricity is used and too much harmful waste is generated in laboratory classes. This highlights a very poor understanding of ecological issues by the students.

Tab.1. Results of the Shapiro-Wilk W and Shapiro-Wilk p test for individual questions.

	W	P
Sex	0.496	<.001
Age	0.799	<.001
Field of study	0.892	<.001
Level of study	0.759	<.001
1. I believe that doing traditional laboratory experiments in chemistry classes is necessary.	0.629	<.001
2. I feel safe during chemistry lab classes.	0.791	<.001
3. During chemistry laboratory classes, I am afraid to perform chemical experiments on my own.	0.859	<.001
4. During chemistry laboratory classes, I am afraid of heating substances with a burner on my own.	0.837	<.001
5. During chemistry laboratory classes, I am afraid to use concentrated substances myself.	0.858	<.001
6. I believe that too many chemical reagents are used in chemistry laboratory classes.	0.790	<.001
7. I think that too much water is used in chemistry labs.	0.879	<.001
8. I believe that too much electricity is used during chemistry lab classes.	0.807	<.001
9. I believe that chemistry laboratory classes produce too much harmful waste.	**0.923**	0.006
10. I believe that the use of MICROSCALE (DROP ANALYSIS) in chemistry laboratory classes is essential.	**0.915**	0.003
11. I believe that the use of MICROSCALE (DRIP ANALYSIS) in chemistry laboratory classes results in less reagent use.	0.876	<.001
12. I believe that using MICROSCALE (DROP ANALYSIS) in chemistry laboratory classes results in less waste.	0.859	<.001
13. I believe that the use of MICROSCALE (DRIP ANALYSIS) in chemistry laboratory classes will increase my sense of safety during classes.	**0.934**	0.014
14. I believe that the use of MICROSCALE (DROP ANALYSIS) in chemistry laboratory classes will make me more willing to perform experiments on my own during classes.	**0.925**	0.007
15. I believe that the use of a MICROWAVE OVEN in chemistry laboratory classes is essential.	**0.918**	0.004
16. I believe that the use of a MICROWAVE OVEN in chemistry laboratory classes results in less reagent use.	**0.899**	0.001
17. I believe that using a MICROWAVE OVEN in a chemistry laboratory class results in less waste.	**0.923**	0.006
18. I believe that using a MICROWAVE OVEN during chemistry laboratory classes will increase my sense of safety during classes.	**0.934**	0.015
19. I believe that using a MICROWAVE OVEN in chemistry laboratory classes will make me more willing to perform experiments on my own during classes.	**0.924**	0.007
20. I believe that using a MICROWAVE OVEN in chemistry laboratory classes will result in lower energy consumption.	**0.928**	0.009
21. I believe that the use of MICROSCOPE in chemistry laboratory classes is essential.	0.878	<.001
22. I believe that the use of a MICROSCOPE in chemistry laboratory classes results in less reagent use.	**0.924**	0.006
23. I believe that using a MICROSCOPE in a chemistry laboratory class results in less waste.	**0.929**	0.009
24. I believe that using the MICROSCOPE during chemistry laboratory classes will increase my sense of safety during classes.	**0.916**	0.003
25. I believe that using the MICROSCOPE during chemistry laboratory classes will make me more willing to perform experiments on my own during classes.	**0.911**	0.002
26. I believe that the use of ONLINE LABORATORIES in chemistry laboratory classes is essential.	0.898	<.001
27. I believe that the use of ONLINE LABORATORIES in chemistry laboratory classes results in less reagent use.	0.785	<.001
28. I believe that using ONLINE LABORATORIES in chemistry laboratory classes results in less waste.	0.784	<.001
29. I believe that the use of ONLINE LABORATORIES in chemistry laboratory classes will increase my sense of safety during classes.	0.864	<.001
30. I believe that the use of ONLINE LABORATORIES in chemistry laboratory classes will make me more willing to perform experiments on my own during classes.	**0.900**	0.001
31. I believe that ON-LINE LABORATORIES should replace ALL chemistry laboratory classes.	0.621	<.001
32. Have you heard the term GREEN CHEMISTRY?	0.587	<.001
33. I believe that the principles of green chemistry must be applied during laboratory classes.	0.833	<.001
34. If you were to choose a field of study again, would you pay attention to whether the field has a "green chemistry" certificate?	0.868	<.001

The second part of the research concerned the use of microscale techniques and droplet analysis during laboratory classes. SSC is a technique to support experimental chemistry teaching. It involves working with small amounts of chemicals, which increases the safety of the experiment, reduces the time it takes to conduct it, allows for a more detailed discussion, and is also less harmful to the

environment. SSC also includes droplet analysis, which is one of the methods of qualitative microanalysis (Orliński, 2013; Tananaev, 1956). The essence of the method lies in the fact that droplets of the test solution and reagent are used for the analysis. During the lectures, students learned about the principles of this technique and then designed and performed experiments using it themselves. It was examined whether, according to students, the use of microscale techniques and droplet analysis during laboratory classes is necessary, whether it causes less consumption of chemical reagents and waste, whether it increases their sense of security, and whether it will make them more willing to perform experiments on their own - compared to "classic" laboratory classes. (Tab. 3.). As our results shows, slightly more than half (59.1%) of students believe using microscale techniques and droplet analysis in laboratory classes results in less consumption of chemical reagents and less waste. 36.4% believe that it increases their sense of safety and is necessary. However, only 25% believe using microscale techniques and droplet analysis in laboratory classes will make them more willing to conduct experiments on their own - compared to "classic" laboratory classes.

Tab. 2 Students' answers to questions 1 – 9.

	I DEFINITELY AGREE	I AGREE	I AGREE PARTIALLY	I HAVE NO OPINION	I PARTIALLY DISAGREE	I DO NOT AGREE	I STRONGLY DISAGREE
Performing traditional laboratory experiments in chemistry classes is necessary.	63.6%	20.5%	9.1%	0.0%	4.6%	2.3%	0.0%
I feel safe during chemistry lab classes.	29.6%	50.0%	13.6%	2.3%	4.6%	0.0%	0.0%
I'm afraid to do my own chemical experiments.	2.3%	6.8%	22.7%	6.8%	6.8%	27.3%	27.3%
I'm afraid of heating the substance myself with a burner.	4.6%	6.8%	20.5%	0.0%	11.4%	25.0%	31.8%
I'm afraid to use concentrated substances myself.	6.8%	4.6%	18.2%	4.6%	11.4%	27.3%	27.3%
In chemistry lab, too many reagents are used.	9.1%	4.6%	11.4%	4.6%	4.6%	29.6%	36.4%
In chemistry lab, too much water is used.	0.0%	6.8%	13.6%	13.6%	11.4%	31.8%	22.7%
In chemistry lab, too much electricity is used.	2.3%	2.3%	2.3%	15.9%	6.8%	34.1%	36.4%
In chemistry lab, too much harmful waste is generated.	6.8%	6.8%	13.6%	15.9%	18.2%	25.0%	13.6%

Tab. 3. Students' answers to questions 10 - 14 concerning the use of microscale techniques and droplet analysis during laboratory classes.

Use of microscale techniques and droplet analysis during laboratory classes …	I DEFINITELY AGREE	I AGREE	I AGREE PARTIALLY	I HAVE NO OPINION	I PARTIALLY DISAGREE	I DO NOT AGREE	I STRONGLY DISAGREE
... is necessary.	13.6%	20.5%	34.1%	27.3%	2.3%	2.3%	0.0%
... results in less consumption of chemical reagents.	27.3%	31.8%	13.6%	22.7%	2.3%	2.3%	0.0%
... creates less waste.	25.0%	34.1%	9.1%	27.3%	4.6%	0.0%	0.0%
... increases my sense of security.	13.6%	22.7%	13.6%	25.0%	11.4%	9.1%	4.6%
... will make me more willing to do my own experiments.	11.4%	13.6%	15.9%	31.8%	4.6%	11.4%	11.4%

The third part of the research concerned the use of a microwave oven during laboratory classes. For example, in Czech publications, we find experiments with the use of microwaves in chemistry lessons (e.g. heating of metals, synthesis of aspirin, synthesis of soap, synthesis of fluorescent dyes) (Šulcová & Nývltová 2004a; 2004b; Šulcová & Böhmová 2007a; 2007b). The answers to our questions about the use of microwave ovens in chemistry laboratories are shown in Table 4.

Tab. 4. Students' answers to questions 15 - 20 concerning the use of microwave ovens during laboratory classes.

I believe that the use of a microwave oven in chemistry lab classes...	I DEFINITELY AGREE	I AGREE	I AGREE PARTIALLY	I HAVE NO OPINION	I PARTIALLY DISAGREE	I DO NOT AGREE	I STRONGLY DISAGREE
... is necessary.	6.82%	11.36%	25%	27.27%	9.09%	20.45%	0%
... results in less consumption of chemical reagents.	-	4.55%	25%	40.91%	6.82%	15.91%	0%
... creates less waste.	4.55%	9.09%	13.64%	38.64%	9.09%	22.73%	2.27%
... increases my sense of security.	6.82%	2.27%	18.18%	27.27%	13.64%	20.45%	11.36%
... will make me more willing to do my own experiments.	4.55%	13.64%	11.36%	27.27%	6.82%	22.73%	13.64%

43.18% believe using a microwave oven during laboratory classes is necessary, and 27.27% believe that it increases their sense of safety. 36.37% believe that it results in less use of chemical reagents and 27.28% that it causes less waste. 25.01% believe it will result in lower energy consumption. Only 30% believe using a microwave oven in laboratory classes will increase their willingness to conduct experiments independently.

The next question concerned the use of a microscope. The results of answers to questions about the use of a microscope in chemical laboratories are presented in Table 5. 70.43% believe using a microscope during laboratory classes is necessary, and 29.55% believe that it increases their sense of security. 52.27% believe that it results in less use of chemical reagents and 47.72% that it causes less waste. 43.18% believe using a microscope during laboratory classes will increase their willingness to conduct experiments on their own.

Other techniques used during classes were online laboratories and simulations (Krebs, 2023; Teplá & Distler, 2023). 40.9% believe using online laboratories or simulations in laboratory classes is necessary, and 59.1% believe that it increases their sense of safety. 77.3% believe that it results in less use of chemical reagents and 72.7% that it causes less waste. 31.8% believe using online labs or simulations in lab classes will increase their willingness to conduct experiments on their own (Tab. 6). However, most respondents (81.1%) believe that online laboratories and simulations should not replace all existing exercises in chemistry laboratories.

The last part of the research concerned students' attitudes towards green chemistry. During their bachelor studies, most students (68.2%) did not come across the term "green chemistry" either during chemistry classes or during classes on environmental protection or sustainable development. But people who answered question 32 (Have you heard the term green chemistry?) stated that they knew this term and in answer to question 33 (Define the term green chemistry) gave the correct definition of this term. Even more surprising are the students' answers to question 34: If you had to choose your field of study again, would you pay attention to whether this field has a "green chemistry" certificate?' For more than half of the students (52.3%), it does not matter whether the studies they participate in are environmentally friendly. Only one-third of respondents (34.1%) agreed with that statement (Fig.1).

Tab. 5. Students' answers to questions 21 - 25 concerning using a microscope during laboratory classes.

I believe that the use of a microscope in chemistry lab classes...	I DEFINITELY AGREE	I AGREE	I AGREE PARTIALLY	I HAVE NO OPINION	I PARTIALLY DISAGREE	I DO NOT AGREE	I STRONGLY DISAGREE
... is necessary.	20.45%	25%	25%	0%	15.91%	11.36%	2.27%
... results in less consumption of chemical reagents.	13.64%	27.27%	11.36%	27.27%	9.09%	9.09%	2.27%
... creates less waste.	11.36%	25%	11.36%	29.55%	9.09%	11.36%	2.27%
... increases my sense of security.	9.09%	15.91%	4.55%	43.18%	9.09%	13.64%	4.55%
... will make me more willing to do my own experiments.	11.36%	25%	6.82%	29.55%	6.82%	9.09%	11.36%

Tab. 6. Students' answers to questions 26 - 30 concerning using online laboratories or simulations in laboratory classes.

I believe that the use of online lab & simulations in chemistry lab classes...	I DEFINITELY AGREE	I AGREE	I AGREE PARTIALLY	I HAVE NO OPINION	I PARTIALLY DISAGREE	I DO NOT AGREE	I STRONGLY DISAGREE
... is necessary.	6.8%	11.4%	22.7%	6.8%	13.6%	15.9%	22.7%
... results in less consumption of chemical reagents.	43.2%	22.7%	11.4%	15.9%	0.0%	2.3%	4.6%
... creates less waste.	43.2%	25.0%	4.6%	18.2%	2.3%	2.3%	4.6%
... increases my sense of security.	27.3%	18.2%	13.6%	18.2%	2.3%	6.8%	13.6%
... will make me more willing to do my own experiments.	11.4%	11.4%	9.1%	15.9%	13.6%	15.9%	22.7%

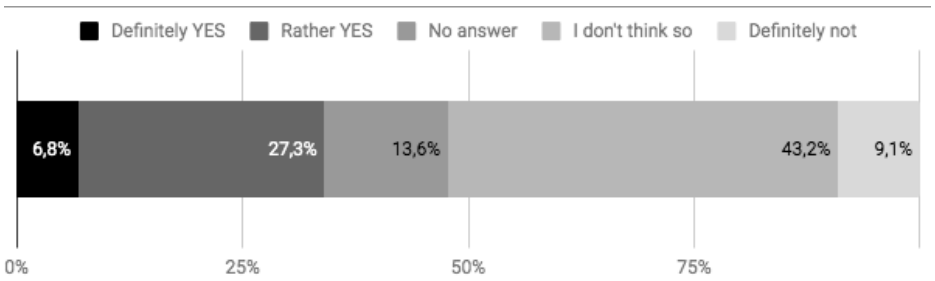

Fig. 1. Students' answers to question 34: If you had to choose a field of study again, would you pay attention to whether the field has a "green chemistry" certificate?

Considering that we are talking about students - future chemistry teachers, the results of the answers to the last question are very disturbing: I believe that the principles of green chemistry should be applied during laboratory classes. More than half of the students (52.3%) have no opinion on whether the rules of green chemistry should be applied during laboratory classes. Only 43.2% of respondents agree with this thesis (including only 11.4% who definitely agree) (see Fig. 2.).

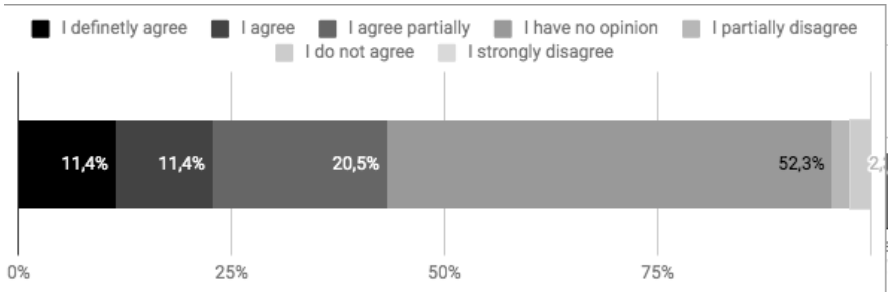

Fig. 2. Students' answers to question 35: I believe that the principles of green chemistry must be applied during laboratory classes

DISSCUSION

Although the principles of green chemistry are popular, teachers must do a lot of work to adapt and translate the principles of green chemistry, regarding industry, into appropriate school experiments (Nahlik et al., 2023). There are no guides for teachers on how to do this, and there are no classes on this subject at universities. Therefore, the research was undertaken to check whether there is a real possibility of replacing school chemical experiments with a more ecological version and what students - future chemistry teachers - think about it. Research on teachers and future chemistry teachers in terms of their knowledge and attitudes toward green chemistry was conducted, among others, by Basheer et al. (2023). Their results showed that teachers' awareness of sustainable development and green chemistry was generally low and depended on years of experience. This means that students do not acquire this knowledge from their studies - this conclusion was also confirmed by our research.

Also, like Karpudewan and Kulandaisamy (2018) we designed and tested green chemistry experiments for their application in teaching chemistry at schools - in this case the results were also confirmed. Respondents found that the green chemistry experiments were consistent with the current curriculum, feasible to implement, encouraged inquiry, were safe, and relevant. However, we were unable to confirm the results obtained by Karpudewan et al. (2012) where the group of students (future teachers) conducting "green experiments" were more internally motivated than the group conducting traditional experiments. We can therefore conclude that our research results are consistent with the research of other, before mentioned scientist’s work.

By analysing in detail, the students' answers to individual questions, we can conclude that the answers of the surveyed students to questions 1 & 2 show that after completing compulsory chemistry classes in bachelor's studies, students believe that chemistry laboratory classes are necessary, and they feel safe during them. Most of them are not afraid to experiment on their own and use a burner and concentrated solutions (compare answers to questions 3, 4 & 5). However, when we compare the students' answers to question 2 with the answers to questions 3, 4, and 5, we see a clear decrease in the number of positive answers (93.2% feel safe in chemistry laboratories vs. 60-70% feel safe performing experiments on their own, using a burner or concentrated solutions). This means that despite the declarative general sense of security (answer to question 2) when we ask about specific laboratory activities, the level of students' safety decreases. Moreover, students do not agree with the statement that typical laboratory classes use too many reagents, too much water, too much electricity, and produce too much harmful waste (see answers 6, 7, 8, 9). This is probably because during the 3 years of chemical education during their bachelor's studies, none of the academic teachers brought this problem to their attention. However, they believe that the use of new techniques: microscale and drop analysis, microscope, microwave oven, simulations, and online laboratories reduce the consumption of reagents and generate less waste compared to traditional laboratories. Since most students feel safe during typical laboratory classes, they do not believe that the use of these techniques will affect their level of safety. A similar situation occurs with the "willingness to perform experiments" - although they consider new techniques interesting, they claim that it does not affect their level of motivation to perform tasks. Therefore, it can be concluded that students positively evaluate the new green methods of conducting classes and believe that laboratory classes conducted in this way will be less burdensome for the environment.

CONCLUSION

The results show that it is possible to replace traditional laboratory classes with more environmentally friendly ones, but after 8 years of traditional chemistry learning, students did not notice the harmfulness of traditional teaching experiences (consumption of large amounts of reagents, water, and electricity, or generation of harmful waste). Therefore, they do not perceive that it is necessary to replace traditional experiences more widely with more ecological versions. It seems that it is necessary to first show academic teachers the burden of traditional laboratory classes on the environment so that they can then properly shape students' attitudes. At the Pedagogical University in Krakow, this topic was dealt with by Justyna Mikołajczyk, MA in her bachelor's thesis (2021): Sustainability in STEM education - insights in the biology teachers' curricula and master's thesis (2023): Sustainable development in the eyes of students and academic teachers of the Institute of Biology and Earth Sciences UP and in publication Mikołajczyk & Nodzyńska (2024).

Particularly shocking are the answers to questions about the course having a "green chemistry certificate" and the need to apply the principles of green chemistry during laboratory classes. Only ⅓ of students would pay attention to the certificate, and more than half of the students (52.3%) have no opinion on whether the rules of green chemistry should be applied during laboratory classes. Therefore, it seems that when it comes to the education of future chemistry teachers, starting from the first laboratory classes, special attention should be paid to the ecological aspect of said education. Elements of green chemistry should also be introduced in primary and secondary school education. The results of this study suggest that green chemistry can and should be integrated into mainstream chemistry education.

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Title: Project-based Education and other activating Strategies in Science Education XXI.

Year and Place of Publication: 2024, Prague

Editors: Dominika Koperová, Martin Rusek

Computer Processing: Dominika Koperová

Published by: Charles University, Faculty of Education

ISSN 2695-0626