Journal of Innovation in Psychology, Education and Didactics
ISSN: 2247-4579, E-ISSN: 2392-7127
http://www.jiped.ub.ro/
Covered in : EBSCO, CEEOL, ProQuest, DOAJ, Scipio,
International Innovative Journal Impact Factor, CiteFactor,
EuroPub database, Open Academic Journals Index, ResearchBib,
Universal Impact Factor
2021, Volume 25, Issue 1, pages: 75-86, doi:10.29081/JIPED.2021.25.1.08

Chemistry Outreach – Reaching Out to Students and Laypeople

Anca-Elena ANGHEL [1]*, Roxana S. TIMOFTE [2]*

Received: 17 March 2021/ Accepted: 26 May 2021/ Published: 28 June 2021

Abstract

Science communication is a promising means for improving the awareness and understanding of scientific concepts by the public, therefore facilitating the transition towards a society consisting mainly of functional adults, capable of making informed decisions, less susceptible to pseudoscientific currents. Science outreach initiatives are a form of science communication that can be used to educate both students and the general public in an informal context, by employing entertaining activities, matched to the knowledge level of the target audience, and emphasizing the impact of science on day-to-day life. By mostly incorporating hands-on activities, science outreach events foster a sense of self-efficacy in the participants, which in time may lead to increased interest towards science and the likelihood that the participants may seek science-related activities themselves.

Key words: Addressing pseudoscience; chemistry outreach; science communication; student affect

---

How to cite*:* Anghel, A.-E., Timofte, R. S. (2021). Chemistry Outreach – Reaching Out to Students and Laypeople. *Journal of Innovation in Psychology, Education and Didactics*, 25(1), 75-86. doi:10.29081/JIPED.2021.25.1.08

[1] Chemist, Babeș-Bolyai University, Cluj-Napoca, Romania, E-mail: ancu.anghel@gmail.com
[2] Lecturer PhD, Babeș-Bolyai University, Cluj-Napoca, Romania, E-mail: roxana.timofte@ubbcluj.ro
* Corresponding author

1. Science communication

Science communication can be defined as the use of dialogue, suitable activities, media resources and suitable abilities in order to elicit one or more of the following responses in the participants: science awareness, science understanding, interest in science, enthusiasm towards science. In order to be successful, a science communication initiative should have predefined and suitable goals, an aspect that is largely influenced by the target audience – the knowledge level of the public, their interests, their socio-economic status, their learning styles, etc. Science communication can be mistakenly perceived as a monologue, in which the central role belongs to the facilitators of such initiatives, members of the scientific community or people working in industry. However, the role of the target audience should not be neglected, since members of a community have a better understanding of the problems they face on a daily basis and might manifest interest towards solving them. While in an ideal setting scientific concepts would be learned in a formal context, during the years of compulsory education, in reality this process is hindered either by overcrowded curricula or by a perceived lack of relevance of the abstract concepts to day-to-day life (Burns et al., 2003).

Effective science communication, both at High School and undergraduate academic levels, can lead to a better understanding of the nature of science and of research pursuits. An emphasis on the relevance of science and chemistry in everyday life can lead to a better retention of underrepresented groups in STEM. In this context, women appear to be prone to switch research fields or opt for teaching positions so as to have a fulfilling career, centred on human connection and impact. By shifting the focus of classical chemistry lessons towards the beneficial changes it can bring to the world, more female students might feel determined to pursue chemistry as a major or as a career choice (Grunert & Bodner, 2011).

2. Outreach activities to eradicate the spread of pseudoscience

The need to eradicate the spread of pseudoscience and to alter the population's mistrust of scientists is more obvious nowadays than ever. In 2020 six scientists offered tips to tackle these issues and to reach out, by pursuing outreach activities. These tips are: show the world who scientists are, tell a good story, tell the truth, tackle misinformation, choose doubt over certainty, and share the spirit of science (Mack *et al*, 2020). Thaler & Shiffman (2015) identified two strategies which can be employed by scientists who are interested in addressing the spread of bad science, pseudoscience and fake science: the audience builder and the expert resource. The development of a large, active and sustaining social media audience appears to be a better strategy, than the growth of a small, niche audience. Scientists should be involved more in activities which minimize public misinformation. However, empirical data showed that there are factors which play a role in the participation of scientists in outreach activities, such as university and disciplinary rewards, and scientists' own perception on their skills (Ecklund et al., 2012). Furthermore, in a study which spanned from 2014 to 2016, the conclusions from focus groups revealed that there are a few barriers and enablers regarding the participation of scientists in outreach activities (Cerrato et al., 2018). Among the motivating factors were: 'to improve personal communication skills; curiosity, fun, need of a break from the daily routine; commitment towards society; to promote science in society at large; to promote a better image of scientists; to seed the love of science in children; to foster social inclusion; to help critical thinking; to encourage children to consider a career in science' (Cerrato et al., 2018, pp. 317). The participants in the focus group activities revealed that the following benefits were unexpected: 'had a positive emotional experience; opened up one's mind to different perspectives; become a better scientist: understand topics much better; improve research competence, get new ideas; become a better person' (Cerrato et al., 2018, pp. 317). The enablers for participating were: 'past behaviour (positive experiences); networking ('the more, the better'); encouraging environment (sharing passion and interests); professional training in communication of science; direct participation in planning and evaluating activities; strong commitment of the institutions; some official recognition' (Cerrato et al., 2018, pp. 318). The barriers to participation were: 'lack of volunteers (feeling alone); lack of communication skills; professional instability; financial instability; sceptical environment (mild hostility of the supervisors); the negative political situation in the country' (Cerrato et al., 2018, pp.318).

3. Student affect

How students feel while learning chemistry impacts their behaviour and their performance. The attitudes of students towards science is influenced by personal factors (such as self-confidence, enthusiasm, feelings of anxiety, fear of failure, past performances, gender, age, professional interests) as well as by extrinsic factors (the attitude and enthusiasm of the teacher and of the peers, the learning environment, the influence of their parents, the grading system, future enrolment in national examinations) (Adesoji, 2008; Cheung, 2011; Hofstein et al., 2011). The generally negative attitudes of students toward chemistry and their decreasing interest in learning this subject may arise from the fact that the curriculum is overcrowded, and the emphasis is generally placed on studying abstract concepts, with no apparent connection to one another. In addition, teachers tend to adopt classical teaching methods, in the detriment of novel, more interactive instructional approaches, either from fear of failure or from insufficient instruction in this direction (Hofstein et al., 2011).

While attitude appears to be the most studied affective construct in chemistry education research, other factors such as self-efficacy beliefs, self-concept, effort beliefs, motivation, expectations, values and interest influence students' behavioural tendencies and test results. Affective chemistry research has a few main directions, including comparing and quantifying affective states between different demographic groups in various contexts, assessing the impact of learning interventions on affective states, establishing correlations between measured affective states and examination performance and generating and validating scales for chemistry education research. However, regarding learning interventions, improving affective states appears to be only a by-product of such interventions, with their main focus being on improving knowledge acquisition and the overall learning process (Flaherty, 2020).

Self-efficacy beliefs contribute to a student's confidence in their abilities to bring a task to completion competently. In the context of chemistry education, they may concern cognitive skills, psychomotor skills, or an understanding of the day-to-day applications of the abstract concepts that are studied (Flaherty, 2020). Self-efficacy beliefs play an important role in the choice of a career or academic pathway in women, and are shaped by four main factors: tasks completed successfully in the past, peer observations, verbal or non-verbal feedback and psycho-affective states. By impacting the way in which knowledge is built and the relevance attached to it, the learning environment and social interactions also play a role in shaping the self-efficacy beliefs. Such beliefs are positively correlated with good class performance, confidence in one's chemistry knowledge and prior satisfactory research experiences. However, they are negatively influenced by uninformed peer comparisons, which can lead to feelings of inadequacy and psycho-affective states resembling the impostor syndrome. Apart from self-efficacy beliefs, value judgements regarding career options have a significant impact on the career decision making process in women, with many of them perceiving as fulfilling a profession involving human connection and societal impact. Opting for a teaching position or for a research career in another field than chemistry, such as physiology or medicine, stems from the fact that women may not perceive research in chemistry as having a considerable, beneficial impact on society, in a measurable time scale (Grunert & Bodner, 2011).

Another dimension of the affective state that can influence learning outcomes is self-concept, the beliefs a person considers to be true about their experience. Higher self-concept can lead to better examination performances and an in-depth understanding of the abstract notions with which chemistry operates. It is influenced by the relationship between students and educators and it is interconnected with one's self efficacy beliefs. For example, self-concept can be a predictor of the performance at the first evaluation during a semester, which in turn can become a predictor of self-efficacy beliefs regarding the studied subject (Flaherty, 2020). Expectations and values can also contribute to a meaningful, satisfactory learning experience. If the students perceive their learning process as valuable, this aspect can shift their behaviour and impact their performances and future career plans. In a laboratory setting, their expectations can shape them into either information recipients or active learners and innovators (Flaherty, 2020).

Various strategies have been developed to improve the attitude and interest of students in chemistry. The vast majority of these interventions involve shifting the direction of chemistry education towards an authentic, relevant, contextualized and significant experience (Hofstein et al., 2011). One such strategy involves using a historical approach in teaching chemistry, focusing on the developments of the field over time, major discoveries and events. This strategy is motivated by the observation that students' knowledge of chemistry before teaching resembles the knowledge of scientists in Antiquity, being based mostly on empirical or intuitive observations. Therefore, students tend to believe only what they can detect through their senses, an aspect that explains their confusion regarding abstract notions such as atom, molecule, matter. Such an approach would make students aware of the role of chemistry in the rise of certain cultures, of the evolution of the cognitive capacities of people, as well as of their constant efforts for self-improvement. This strategy could also appeal more to students that do not plan on choosing a career in STEM, and have more interest towards the humanities (Hofstein et al., 2011). Another approach involves the use of practical activities, which are advantageous because they lead to the development of practical skills and self-confidence in students. By using hands-on experiments, students may feel that they are able to discover something themselves, which can motivate them to search for more information on the studied topic, developing a more positive attitude towards chemistry. In addition, inquiry-based activities, rather than confirmation-type activities are more useful in stimulating critical thinking and problem-solving skills of students, as well as cooperative learning. This final aspect is important in developing team spirit and the feeling of belonging to a community (Hofstein et al., 2011).

Instruments aiming to quantify students' attitude towards chemistry mainly focus on their interest for the subject, their perception on its usefulness in everyday life, the anxiety or enjoyment they may experience while learning chemistry or on how accessible they perceive it from an intellectual perspective. Higher-achieving high school students tend to have more positive attitudes toward learning chemistry, which in time favours autonomous learning. At universities, more positive attitudes towards learning general chemistry translate into an increased probability of pursuing additional chemistry courses in the future (Flaherty, 2020). However, attitude evaluation is made difficult by their subjective nature and by the fact that their formation may only be deduced from observable responses: affective responses (feelings, emotions), cognitive responses (beliefs) and behavioural tendencies. A useful instrument in the quantification of attitudes is the Attitude toward Chemistry Lessons Scale (ATCLS) (Cheung, 2011), a Likert-type scale comprising 4 subscales. The first subscale monitors students' feelings towards theoretical lessons, the second subscale verifies the preference of students for practical activities in the chemistry laboratory, the third subscale monitors the evaluative beliefs of students regarding the usefulness of chemistry in day-to-day life, while the fourth subscale focuses on the behavioural tendencies of students as a response to chemistry lessons taught in school. Such a scale can be used to monitor the efficiency of the teaching strategy of professors, as well as for mapping students' attitude towards chemistry over time, offering the possibility of adapting and optimizing the instructional strategies accordingly (Cheung, 2011).

4. Chemistry outreach

By encouraging chemistry learning in an informal, enjoyable context, outreach initiatives facilitate the development of situational interest in chemistry, even in the case of lower-achieving students, since the planned activities usually focus on the subject's relevance in everyday life. Maintained situational interest can lead to an increased probability of involvement in experimental procedures which in turn can lead to a better understanding of the underlying abstract chemical concepts (Flaherty, 2020).

Outreach activities designed for High School levels have the potential of determining young females to pursue science, or in particular chemistry, as a major or career path (Grunert & Bodner, 2011). Outreach initiatives aimed at increasing the number of female students in STEM fields have been reported in the literature. However, women continue to be underrepresented in such fields. Despite the fact that almost half of chemistry bachelor students in the USA in 2011 were women, this figure decreased progressively in the context of master's degrees, graduate studies and postdoctoral positions occupied by females. These findings emphasize the need for a better understanding of the career decision making process in women, as well as for development of retention strategies for them in STEM (Grunert & Bodner, 2011).

4.1 Advantages and challenges of outreach activities

By primarily targeting middle school or high school students and involving them in hands-on activities in university laboratories, outreach activities facilitate an understanding of the applicability of chemistry in day-to-day life. Students may encounter a new face of chemistry, one that is engaging, fun, different from the unapproachable side of this subject discovered in formal educational settings. In formal settings a lack of funding usually makes the purchase of laboratory equipment or chemical substances impossible (Bodsgard et al., 2011).

Generally, the efficiency of chemistry outreach initiatives is evaluated with regard to their impact on the attitudes, interests and behaviours of participants towards chemistry. However, these activities may also be advantageous for their facilitators. They can lead to an improvement in their communication skills, enabling them to explain abstract concepts in lay language, to integrate flexibility in their explanations and to focus on establishing connections between these notions and real life. In addition, volunteers taking part in outreach activities can improve their time management skills, their abilities to design curriculum according to the knowledge level of their target audience and they may become more aware of the problems faced by individuals in their community that are not part of academia (Gagnon & Konor, 2017; Burns et al., 2003.) In the case of outreach activities designed for students from disadvantaged environments, facilitators may also become aware of the challenges and limitations faced by the educational system there and, through their involvement in the programs, become role models for the young participants. Such connection between students and PhD volunteers could motivate graduate students to pursue a career in science education (Harrison et al., 2011).

However, the development of chemistry outreach activities also faces numerous challenges. Since it is desirable that the activities reach as many students and teachers as possible, while including quality content, and since the facilitators are generally students or graduates, one of the challenges is represented by the need to train an adequate number of PhD or master students to deliver the contents to the target audiences. By doing this, the negative impact of dedicating large amounts of time to outreach activities' preparation upon their studies can be reduced. Furthermore, the likelihood that they may experience burnout decreases. Apart for the needed financial support, it is also desired for the projects to have a long-term nature and to expand over time, reaching an ever-increasing number of people. This aspect can be solved by offering free transportation for the facilitators to the schools included in the program and, in time, by also training local teachers to become the mentors of the outreach activities (Harrison et al., 2011).

Regarding hands-on experiments, special time must be allotted to choosing adequate experiments and to testing them (Bodsgard et al., 2011). Ideally, the experiments should be captivating and fun, stimulating the curiosity of the students and their interest towards science, but they should not exceed by much the knowledge level of the target audience, so as not to be perceived as discouraging, impossible to understand. In the case of this type of chemistry outreach, students must be instructed at the beginning of the activity with regard to safety issues in the laboratory and provided protective equipment (lab coats, gloves, safety goggles).

In the context of integrating outreach activities and green chemistry, while educators acknowledge the importance of students understanding what chemical hazards are and what risks they pose, difficulties that arise when trying to include sustainability issues in the curriculum include: lack of funding, an already overcrowded curriculum, lack of training for educators – since they would need to keep up to date with technical knowledge, lack of adequate teaching resources, as well as the costs of developing new educational resources (MacKeller et al., 2020).

Generally, in the context of science outreach and science communication, another challenge consists in including in the interventions both introductory concepts, that would attract an uninformed audience and variety to capture the interest of informed people, as well as a reinterpretation of contents to surprise experts in the field (Burns et al., 2003).

4.2 Outreach activities involving both hands-on activities and educational videos

Despite the perceived usefulness of TED-Ed (Technology, Entertainment, Design – Education) videos in teaching complex scientific concepts, they appear to be not widely used in classical teaching settings. A recent study (Finkenstaedt et al., 2018) showed that, outreach approaches involving both TED-Ed videos and hands-on activities were useful in the context of teaching complex subjects, relevant to society, such as climate change. A modular structure of the activity, with key concepts of the subject (albedo, the ozone layer, the greenhouse effect, ocean acidification) treated separately, both from a spatial and temporal perspective decreases the likelihood of confusion between these aspects. A module with a duration of 15-20 minutes can be structured as follows: students are given a pre-test, regarding the concepts that will be studied, they watch a TED-Ed video on the subject, they assist to a demonstration performed by two professionals in the field, they participate in hands-on activities and are finally evaluated again via a post-test, that focuses on both their understanding of the concepts and their confidence in the given answers. Therefore, such an approach can be used in order to identify and eradicate students' misconceptions. Post-tests are also a means for evaluating the efficiency of the outreach approach, proving that the intervention leads to an increased number of students answering the questions correctly and that their confidence levels regarding the given answers are also elevated (Finkenstaedt et al., 2018).

4.3 Celebrating National Chemistry Week and the International Year of Chemistry

Another chemistry outreach initiative reported in the literature involves celebrating National Chemistry Week or the International Year of Chemistry by organizing "Chemistry Nights" on campus. For such complex events, middle school or secondary school students, accompanied by their teachers are actively involved in experiments carefully designed for them in chemistry faculties across the country (Bodsgard et al., 2011). Chemistry Night enables a first contact of the students with the academic environment and might increase their awareness regarding career opportunities that arise after studying disciplines in the STEM field in college.

To ensure the success of the intervention, Chemistry Night is first assigned a theme and then promoted from the beginning of the academic year in the schools from the community. In this context, middle schools and high school teachers may receive promotional materials such as posters to captivate the attention of their students. To facilitate the immersion of students in the academic environment, the event can be structured as a conference, with students and their teachers receiving folders upon arrival, containing the schedule, the list of experiments to be performed, as well as a story to connect the experiments. Given the practical nature of the planned activities, students must be instructed regarding safety measures in the laboratory and be provided protective equipment (lab coats, gloves, goggles). To ensure that students understand the key underlying concepts of the activities, the experiments can be divided in sections, with the transitions between stations conditioned by filling a report. Such interventions are advantageous because they enable deep learning of key concepts in chemistry in a fun and entertaining manner, while encouraging teamwork. Furthermore, university students may act as mentors for the participants, guiding them throughout the event, creating a bond between them and facilitating dialogue. However, one of the setbacks of such events is that, in order to ensure that all participants can be actively involved in the activities, the number of students from each school can be limited (Bodsgard et al., 2011).

4.4 Outreach activities for overachievers – Summer Camps

As a part of the Bristol ChemLabs Outreach Program (UK), a two-week long summer camp was organized in teaching chemistry laboratories at the university for 14–16-year-old high school students with exceptional results in scientific subjects. The approach proved useful in developing the practical skills of the participants, including knowledge on how to safely manipulate laboratory equipment and chemical substances, how to make pertinent observations and how to analyse results (Shallcross et al., 2013). During the summer camp, the students were daily involved in experiments taking place in the chemistry laboratory, under the guidance of PhD students or master students, whom they could find more approachable than college professors. Among the characteristics that ensured the success of this outreach approach are the following: the daily schedule involved a pre-lab session covering the experiments to be performed, for which students needed to prepare in advance; enough time was dedicated to each synthesis or extraction in order to favour in-depth learning; the experiments were interconnected through a central theme, correlated with problems relevant to society, such as nutrition or how medicines work in the body. Thus, students were encouraged to study complex theoretical concepts in a new context, with an accent on inquiry-based learning and deducing laws and principles through investigation. The duration of the Summer Camp enabled the involvement of the students in other outreach activities, such as participating in conferences lead by experts in the fields under study, visiting chemical companies or various departments of the university and even communicating their own results to their peers. The beneficial outcomes of the intervention included students performing the experiments faster and correctly as the days passed, students detecting erroneous data before beginning the experimental procedure and addressing questions about it during the pre-lab sessions, as well as using the extra time to characterize the obtained compounds or to plan future experiments without being required to do so. In addition, time management skills and teamwork spirit were developed in the participants (Shallcross et al., 2013).

4.5 Outreach activities aimed at reducing the gender gap in STEM

The gender gap in STEM is also a reality in academia, with fewer women than men occupying teaching positions in top STEM faculties in the USA in 2012-2013 **(**Levine et al., 2015**)**. In response to this situation, certain science outreach initiatives have focused on target populations consisting only of girls. One such approach, recently reported in the literature (Levine et al., 2015), consists of an intensive one-week long Chemistry Camp addressed to middle school girls, while the facilitators are women in academia, who have opted for a career in STEM. It is believed that the gender disparity in STEM fields has its roots in early education, with primary school girls showing less interest in natural sciences than primary school boys. The possible causes of this tendency are a lack of female role models and the self diminishing beliefs of young girls regarding their abilities to succeed in STEM subjects, as well as the misconceptions of parents, teachers or figures of authority, viewing a career in research as exclusively destined to caucasian males. The Chemistry Camp includes hands-on activities meant to develop the practical skills and self-confidence of young girls, Q&A sessions with females who have chosen a career in STEM, as well as field trips, an opportunity not usually met by students in the context of formal education, due to lack of funding. The experiments can be chosen so as to be relevant to the girls (studying the composition and properties of hair gel, analyzing the pigments present in lipstick or painting T-shirts), while also focusing on the applicability of chemistry in day-to-day life. The discussions with females in academia may offer insights into the purposes of scientific projects or into the daily schedule of a scientist, proving to the participants that the academic environment is more demographically diverse than generally presumed. Apart from these goals, the intervention is also meant to improve the attitude of the participants towards chemistry, an aspect that can be monitored by administering questionnaires pre- and post-intervention. The attitudes and interests can also be traced via follow-up questionnaires, focused on faculty, major and career choice (Levine et al., 2015).

4.6 Outreach activities targeting adults striving for a High School equivalency degree

In 2017, 10% of the adult population of the USA were not high school graduates, an aspect that severely interfered with their job seeking prospects. Many adults in this group strive for a high school equivalency degree, but in order to achieve this must pass a series of tests that include a science section. Since these adults generally belong to low-income families, minorities or disadvantaged populations, they could be the target audience of science outreach initiatives, but are rarely included in such informal learning activities organized by universities (Gagnon & Komor, 2017). SciMentors is an outreach program destined to this group that aims at including hands-on activities in the science lessons taught to adults preparing for high school equivalency tests. The program responds to two primary needs in this community: understanding of the scientific concepts and developing critical thinking skills. Given the practical nature of the program and the fact that it is facilitated by PhD or postdoctoral students, the participants are more likely to establish correlations between scientific concepts and day-to-day problems. The program does not focus on recruiting people for STEM careers, but rather on increasing scientific literacy and turning the participants into functional citizens, capable of making informed decisions. It is designed to include frequent meetings with the target audience and to have a student to teacher ratio of approximately 4:1. Before each hands-on activity, a short discussion on the topic under study takes place, in order to clarify the science behind the phenomenon or the process. Then, the class is divided into small groups and each of them is assigned a volunteer that will demonstrate the experiment, facilitate discussions between the students from the group and answer their questions. At the end of the activity, the class will reunite and shortly discuss what they have learnt. An advantage of organizing the activities in small groups is that collaboration and communication between members of the group are encouraged, an important aspect since adult learners might experience discomfort when trying to speak in class, either because of past negative experiences in school, being previously shamed for bad answers or because of the language barrier, in the case of immigrant participants. One of the challenges of the program is the design of experiments suited for an environment that is not destined to practical activities. Therefore, the experiments chosen usually involve the use of low-cost materials, raising few to no safety concerns. The advantages of the program include targeting an audience that has generally reached an age at which the understanding of science is perceived as either boring, confusing or impossible, as well as enabling the facilitators to improve their science communication skills and to design curriculum (Gagnon & Komor, 2017).

4.7 Outreach activities with a focus on Green Chemistry

4.7.1 Green Chemistry

Green chemistry encourages chemists to prevent the generation of waste, to choose synthetic routes leading to a minimum number of by-products, to thoroughly consider the implications of using a certain reactant, while also attempting to maximize the yield of the process (Cannon et al., 2020). The 12 principles of green chemistry (Anastas & Warner, 1998; Cannon et al., 2020) are: 1) preventing rather than managing the synthesis and disposal of hazardous substances; 2) atom economy – selecting synthetic routes that lead to the incorporation of all of the reactants into the final product; 3) using less hazardous chemicals, thus reducing the risk posed to the human health and to the environment; 4) striving for energetic efficacy – reducing the economic and environmental impact of the process by working at room temperature and ambient pressure; 5) if using no solvents and auxiliaries is impossible, trying to use the safest alternatives; 6) designing less harmful chemicals, with a long shelf life and reduced toxicity; 7) reducing the number of steps required for a chemical process; 8) reusing materials; 9) employing catalysts – while the use of catalysts might seem an expensive alternative, their selectivity makes them more advantageous than stoechiometric reactants; 10) if possible, designing biodegradable products, that do not persist in the environment after fulfilling their function; 11) minimizing the risk of potential accidents (explosions, fires, releases); 12) real time analysis of the workflow, with the aim of preventing the release of pollutants in the environment.

4.7.2 Outreach activities with a focus on Green Chemistry

Outreach initiatives with a focus on green chemistry have emerged as a valuable alternative to classical outreach programs. They provide potential for hands-on activities in an informal context, as well as enabling an increase in the awareness of participants regarding the education for sustainable development. In addition to providing access to more environmentally friendly experiences for participants, green chemistry approaches are also safer and less hazardous for both facilitators and beneficiaries (Cannon et al., 2020).

Such interventions are also a means of removing the stigma regarding the portrayal of chemistry as dangerous for the environment. Instead, by using such approaches, the public may become aware of the positive role of chemistry in everyday life and its beneficial impact on society. In outreach initiatives directed towards students, a focus on green chemistry can favour holistic learning, by connecting various subjects studied in school (Cannon et al., 2020). One of the major challenges faced by society nowadays is sustainability. Outreach activities, destined both to the general public and to High School students, could focus on green chemistry approaches, encouraging the audience to incorporate systems thinking in the workplace or in their future careers. However, incorporating green chemistry principles in these interventions is still the exception from the rule (MacKeller et al., 2020), since generally the facilitators focus on demonstrations that could appeal to the public, mostly involving changes in colour, explosions or fire (Cannon et al., 2020). Green chemistry approaches would facilitate creating a safer environment for students to develop their skills and to increase their awareness regarding the impact of their actions or inactions on the environment. In addition, including green chemistry principles in the curriculum could allow educators to teach students about recognizing a hazard, assessing the risk of a hazard, minimizing it and preparing for emergencies (Cannon et al., 2020). While this approach is currently used in universities, usually incorporated in the requirements students must fulfil for pre-lab sessions, including it in High School education could be more useful in fostering awareness in young students than using a work safety session at the beginning of the school year.

Besides the general advantages of adding outreach activities to the curriculum, activities with a focus on green chemistry would increase scientific literacy in students, while promoting their interest in STEM and sustainability. Hands-on activities based on green chemistry approaches could prove safer than the classical ones, while still being entertaining and captivating. An example of such an activity reported recently in the literature involves studying ocean acidification in a cup. Introductory discussions can focus on the contrast between renewable sources of energy and fossil fuels and the excess carbon dioxide in the atmosphere as the main determinant of the greenhouse effect. When discussing acids and bases, a household item (cabbage juice) can be used as an indicator, as opposed to the classical ones. The hands-on activity can be followed by a brainstorming for renewable materials that can capture carbon dioxide, a step that can then start a discussion about the capitalization of waste products to generate new, useful chemicals (Cannon et al., 2020).

4.8 Outreach activities integrating Chemistry and Art

Numerous outreach activities reported in the literature focus on improving the attitudes, interests and/or performances of middle school or high school students in Chemistry or Science. By using an interdisciplinary approach, attempting to bridge chemsitry and art, it has been recently proved that outreach activities can also be adressed to primary school students (Gaquero-Parker et al., 2016). One such activity involves painting with a copper-based pigment and is centered on the synthesis of malachite starting from a copper sulphate solution and solid sodium bicarbonate. The obtained precipitate can be used as a pigment in combination with various binders, such as egg yolk, linseed oil or arabic gum. The experiment is attractive to a young audience, since it involves changes in color and in the phases of matter. It can also be used as a starting point for discussions about the relevance of chemistry in the pigment industry. In addition, it is easy to perform, avoiding the need for complex equipment (it can be done in a sandwich bag) and making use of accessible resources, such as napkins, paint brushes, paper, plastic cups, plastic spoons.

5. Conclusion

Given the interplay between affective states and students' performance in chemistry education, more research appears to be needed in order to uncover the mechanisms by which emotional states regarding learning chemistry can be improved. Learning interventions solely targeted at improving such affective states are lacking, with this outcome being mainly a secondary product of interventions meant to enhance knowledge acquisition. However, communicating science to pupils and citizens is a must, and scientists should not give up on their endeavour to eliminate pseudoscience and reduce the mistrust in scientists.

In this context, chemistry outreach initiatives, targeting either students or the general public, are an attractive route to popularizing science and making it more accessible and entertaining. By focusing on explaining abstract concepts or complex phenomena in an informal setting, using lay language, and by shifting the focus of the learning experience towards the applicability of chemistry in daily life, improved attitudes of the target audience towards chemistry can develop. This, in turn, may lead to increased interest towards scientific concepts or improved feelings of self-efficacy in understanding such concepts. When the target audience consists of students, the outreach events may have an effect on their career choice. However, adults should not be excluded from chemistry outreach initiatives, since their involvement can improve scientific literacy and transform them into informed, functional citizens. Outreach initiatives are also advantageous for the facilitators, enabling them to develop their science communication or time management skills, to design curriculum and to establish a connection with the community.

References

Adesoji, F. A. (2008). Managing students' attitude towards science through problem-solving instructional strategy. *The Anthropologist*, *10*(1), 21-24.

Anastas, P. T., & Warner, J. C. (1998). *Green Chemistry: Theory and Practice*. Oxford University Press: New York.

Bodsgard, B. R., Johnson, T. A., Kugel, R. W., Lien, N. R., Mueller, J. A., & Martin, D. J. (2011). Organizing a high school chemistry outreach event: Celebrating National Chemistry Week and the International Year of Chemistry. *Journal of Chemical Education, 88*(10), 1347-1350.

Burns, T. W., O'Connor, D. J., & Stocklmayer, S. M. (2003). Science communication: A contemporary definition. *Acoustics, Speech, and Signal Processing Newsletter*, *12*(2), 183-202.

Cannon, A. S., Keirstead, A. E., Hudson, R., Levy, I. J., MacKellar, J., Enright, M., Anderson, K. R., & Howson E. M. (2020). Safe and sustainable chemistry outreach activities: Fostering a culture of safety in K-12 and community outreach programs. *Journal of Chemical Education,* Retrieved from https://pubs.acs.org/doi/10.1021/acs.jchemed.0c00128

Cerrato, S., Daelli, V., Pertot, H., & Puccioni, O. (2018). The public engagement scientists: Motivations, enablers and barriers. *Research for All*, *2*(2), 313-322

Cheung, D. (2011). Evaluating student attitudes toward chemistry. Lessons to enhance teaching in the secondary school. *Educación Química*, *22* (2), 117-122.

Ecklund, E. H., James, S. A., & Lincoln, A. E. (2012). How academic biologists and physicists view science outreach. *PLoSONE, 7* (*5*), e36240.

Finkenstaedt-Quinn, S. A., Hudson-Smith, N. V., Styles, M. J., Maudal, M. K., Juelfs, A. R., & Haynes, C. L. (2018). Expanding the educational toolset of chemistry outreach: Providing a chemical view on climate change through hands-on activities and demonstrations supplemented with TED-Ed videos. *Journal of Chemical Education*, *95*(6), 985-990.

Flaherty, A. A. (2020). A review of affective chemistry education research and its implications for future research. *Chemistry Education Research and Practice*, *21*, 698-713.

Gagnon, N. L., & Komor, A. J. (2017). Addressing an overlooked science outreach audience: Development of a science mentorship program focusing on critical thinking skills for adults working towards a high school equivalency degree. *Journal of Chemical Education*, *94*(10), 1435-1442.

Gaquero-Parker, A.C., Doles, N. A., & Parker, C. D. (2016). Chemistry and art in a bag: An easy-to-implement outreach activity. Making and painting with a copper-based pigment. *Journal of Chemical Education*, *93*(1),152-153.

Grunert, M. L. & Bodner, G. (2011): Finding fulfillment: women's self-efficacy beliefs and career choices in chemistry. *Chemistry Education Research and Practice*, *12*, 420-426.

Harrison, T. G., Shallcross, D. E., Norman, N. C., Sewry, J. D., & Davies-Coleman M. T. (2011). Publicising chemistry in a multicultural society through chemistry outreach. *South African Journal of Science*, *107*(11/12), 669-674.

Hofstein, A., & Mamlok - Naaman, R. (2011). High-school students' attitudes toward and interest in learning chemistry. *Educación Química*, *22*(2), 90-102.

Levine, M., Serio, N., Radaram, B., Chaudhuri, S., & Talbert, W. (2015). Addressing the STEM gender gap by designing and implementing an educational outreach chemistry camp for middle school girls. *Journal of Chemical Education*, *92*(10), 1639-1644.

Mack, K., Kruszelnicki, K., Randall, L., Wade, J., Al-Khalili, J., & Vedral, V. (2020). Reaching out. *Nat Rev Phys*, *2*, 282–284.

MacKeller, J. J., Constable, D. J. C., Kirchhoff, M. M., Hutchison, J. E., & Beckman E. (2020). Toward a Green and Sustainable Chemistry Education Roadmap. *Journal of Chemical Education*, *97*(8), 2104-2113.

Shallcross, D. E., Harrison, T. G., Shaw, A. J., Shallcross, K. L., Croker S. J., & Norman N. C. (2013). Lessons in effective practical chemistry at tertiary level: Case studies from a chemistry outreach program. *Higher Education Studies*, *3*(5), 1-10.

Thaler, A. D., & Shiffman, D. (2015). Fish tales: combating fake science in popular media. *Ocean Coast. Manag., 115*, 88–91.