Workshop White Paper

Green Chemistry Experiments for Remote Locations

Belém, Pará, Brazil

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With thanks to:

Contents

Executive summary

Brazil is a large and diverse country. It has characteristics favorable to embedding green chemistry education in schools and universities, including its rich biodiversity and vast availability of natural resources, However, it also presents many challenges including the diverse culture and educational approaches in different regions of the country and the challenging context in many schools, which lack laboratories and experimental classes. The workshop “Green Chemistry Experiments for Remote Locations”, a partnership between the American Chemical Society and the Brazilian Green Chemistry School, brought together teachers, professors and researchers from Brazilian schools and universities with international experts to discuss possible strategies to help spread a practical green chemistry education in Brazil. Challenges identified by participants included:

- The need to develop a curriculum that enable educators to utilize activities relevant to local contexts and the knowledge of students
- The lack of a community of practice for educators in green chemistry
- Educational development or co-production with teachers and students – identify key people that can involve other people is very important
- Ensuring that green chemistry is integrated into the training of chemistry teachers
- Improving the working environment, infrastructure and access to materials and resources for teachers

To overcome these challenges three programmes were proposed as starting points for embedding green chemistry in education in Brazil:

1. **Embed green chemistry in teaching degree education**
2. Developing **a network of Green Chemistry Ambassadors** by selecting and training highly-engaged educators from States across Brazil
3. Developing an **online platform** to share tailored and translated educational materials for use by educators across Brazil
4. Developing an **online training course** for educators and students using blended and interactive materials

The knowledge shared throughout the workshop and the proposed initiatives not only can transform the landscape of green chemistry in Brazil, but also serve as inspiration for projects that work on the theme in other countries with which Brazil has similarities, especially in Latin America and the Caribbean and Africa.

1. Introduction

Chemistry is at the core of nearly all human activities and is vital to economic development and to the creation of new strategies to achieve a sustainable future. Green chemistry or sustainable chemistry aims to foster processes and products that are socially beneficial and utilize resources sustainably. Brazil has a wide range of characteristics that can enable it to be at the forefront of sustainable chemistry as it is rich in biodiversity and natural resources, with intense solar radiation, plenty of water, and varied climatic conditions throughout the country.

1.1 Green Chemistry today

(by Norma Sbarbati Nudelman, University of Buenos Aires, Argentine)

Green chemistry was defined as a set of principles to design a safer product, with a process preventing the use of toxic reagents and producing the smaller amounts of waste materials. However, today, sustainable chemistry goes beyond those goals including other issues, such as: the energy economy, the emission's reduction, the atom economy, the use of renewable energies, the reduction in fossil fuels and organic solvents, the use of natural products as alternative sources, the E-factor greenness of an industrial process, the sustainable use of agrochemicals, biofuels and biocatalysts, etc. Processes designed by green routes help in the promotion of resource and energy utilization efficiently. It involves low level of waste, and is inherently safe making the processes economic

The experience of the Argentine Academy of Sciences in offering theoretical-practical courses on these subjects for secondary school teachers goes back to more than 10 years ago. The first one at a Latin American scale took place in 2004, and since then more than 40 theoretical-practical courses/workshops have been offered. Teachers and students are very enthusiastic for this kind of environmentally friendly chemistry. The workshops also include experiments on green chemistry that can be done with very low-cost and easily accessible resources, and visits to local industrial plants.

Recent initiatives alert on the urgency of applying more environmentally friendly chemicals and processes to mitigate climate change of anthropogenic origin. Some of them are: the letter from the Academies to the WS of Rio+20; the FAO's Program for Food Security to all by 2030; some of the United Nations 17 Sustainable Development Goals 2016-2030; the "Laudato Sii" P. Francis encyclical; the COP21, and the agreement on climate change (Paris, Nov 2015) , and the "Children as agent of change"' initiative in the 2015 Workshop in the Vatican organized by the Pontifical Academy of Science; and the 20th Annual Green

Chemistry & Engineering Conference: “Advancing Sustainable Solutions by Design” (Portland, USA June 2016). All of these initiatives show that sustainable development is not only a matter of science; it is a catalyst for change, an innovative approach to problem-solving and a long-term solution to global sustainability challenges. And it requires a radical redesign of our social behavior, and “bottom-up” voluntary actions: education is essential to achieve both goals.

1.2 Background to Sustainable Development in Brazil

Nowadays, Brazil invests around 1.5% of its GNP on research and innovation. It has several distinguished research centers and universities and is placed 13th in the number of refereed scientific publications. However, on the other hand, Brazil owns less than 0.5% of the world’s patents and was placed 63rd in a recent international education test of science for 15 year-olds. Therefore, there is a contrast between state of the art science initiatives and a poor basic education and technological innovation environment.

Brazil’s GNP oscillates between 6th and 8th in the world and its chemical turnover shows similar trends. However, the treat balance in chemicals is strongly negative and seems to be on the rise. Some internal markets for chemicals are attractive, such as cosmetics, agro chemicals, and food additives for animals.

Petroleum extraction and production is also a relevant activity. Because of recent changes in Brazilian regulations on exploring the large deep and ultra-deep deposits, international oil and service companies are increasingly interested in investing in equipment and materials that can be used in the region.

Other key investment opportunities relates to cellulose, oils, sugarcane, and others. Experts estimate that in 2020, the Brazilian market for chemicals produced from renewable sources could represent as much as 10% of the local chemical industry.

Brazilian energy is already mostly produced by renewable sources, specially hydropower. In addition, the country has successful programs on biofuels such as the ethanol program.

The first car that used ethanol as a fuel in Brazil was launched in 1925. Today, nearly all new cars can run either on ethanol or gas. Life cycle analysis indicate that automobiles totally running on ethanol are almost carbon neutral. It is worth noticing that sugarcane is produced in regions that are distant from protected areas rich in biodiversity, and that there is already a built infrastructure for collection, storage and transport of materials and products.

During the early decades of the twentieth century ethanol was employed in Brazil as a raw material for the chemical industry (producing ethyl chloride, acetic acid, acetic anhydride and a number of other products). Unfortunately, as petroleum prices came down, some of these investments became unattractive, but that does not overshadow the success of the ethanol program. Finally, lessons learned from the ethanol program have also been valuable for the biodiesel production.

In fact, Brazil has taken a leadership position when it comes to developing green chemistry processes and bio-based materials and pharmaceuticals. Brazil was a pioneer large-scale producer of biofuels, bio-based plastics and bio-derived insecticides.

However, vital to this vision is both the development of scientists with the necessary skills and knowledge to develop new research avenues and industries based on green chemistry and a wider public awareness to support the green economy.

1.3 Green Chemistry Awareness in Brazil

While the relation between nature and science has always been in the mind of those who live in a country with such natural richness, the concern to organize and disseminate initiatives to promote sustainable development become more visible in the 1990's.

Short after the Rio Conference on Development and Environment (Rio92), ACS took part on a meeting about chemistry of the Amazon, resulting on a publication about this issue. Another workshop discussed how nature can be a treasured source of high value chemicals and debated the use of biodiversity for sustainable development investigation of bioactive products and their commercial application.

In the following decade, green chemistry definitely gained space in Brazil after a meeting in Fortaleza, Ceará with the participation of the Green Chemistry Institute in 2007. One of the outcomes of this meeting was to officially install the Brazilian Network on Green Chemistry.

The Brazilian Green Chemistry School was created in 2010, aiming both to develop state of the art green chemistry research that can be useful for industries and to train human resources in this area. It has also a key role on society appreciation and acceptance of green chemistry and develops dissemination activities to create a sense of green processes and products.

The United Nations Conference on Sustainable Development (Rio+20) in 2012 brought a lot of media attention for sustainable development and gave a very important incentive for the Brazilian green chemistry programs.

1.4 Green Chemistry Education Initiatives

In the 2010's, green chemistry was included for the first time in the program of the chemistry weeks that happen yearly in universities and schools across Brazil. The initiative started with the National Science & Technology Week 2011, coinciding with the International Year for Chemistry, which theme was "Chemistry for a better world". In the first year, the initiative reached over 25,000 students only in Rio de Janeiro.

One of the activities offered by worldwide institutions in this opportunity was the distribution of a kit for kids to measure water pH in their local areas. Results were gathered to build a map with information about water around the world. In Brazil, the kits proved to be very popular, as they were simple, colorful, relevant to students, and relevant to their local area. As a result, Brazil was the country that registered the biggest number of tests with this kit, which demonstrates the enthusiasm and desire to do practical chemistry and chemistry of relevance.

In the following years, the Brazilian Green Chemistry School developed an increased variety of outreach activities. They were simple and low cost, besides relevant to the local communities. Most programs had also a thematic focus, for instance, carbon dioxide, global warming, climate change, water acidification, processes for CO_2 capturing, bio-based plastics, and solvents.

One of the strategies used by the Brazilian Green Chemistry School to make activities feasible was stablishing partnerships with local companies such as Oxiteno, leader in the manufacture of surfactants and specialty chemicals. The company developed kits to demonstrate how they produce nail polishers and creams using non-toxic components. The activities were then taken to schools and events were students were excited to take part, working with lab clothes and laboratory glasses, mixing substances to make creams and then testing them on their skin.

The Oxiteno partnership helped to raise awareness of the innovation that was happening in Brazil, to show the relevance of this kind of innovation for industries and to demonstrate the development of sustainable materials in chemistry as a career option for students.

Additionally, this program also created training opportunities for undergraduate students to develop science communication skills.

Besides working together with companies, another strategic partnership that had to be stablished in order to foster green chemistry education in Brazil was obviously working together with schools. Between 2013-2014, the Brazilian Green Chemistry School developed partnerships with high schools and technical schools. The main strategy was to bring groups of students aged 14-17 inside the university to visit facilities such as a biorefinary demonstration plant. They were very enthusiastic and very engaged.

Building from this experience, a series of conferences was organized to share and multiply the results.

'Teaching green chemistry in schools' workshops were held in the Brazilian Chemistry Education and Chemistry Congresses in 2014 and 2016. In these opportunities, not only the Brazilian Green Chemistry School presented its projects, but also heard from other professors and teachers about their own experiences.

Green chemistry courses for teachers were offered in different states of Brazil, including Amazonas, Pará, Goiás, and Rio de Janeiro. However, there are still many regions to reach.

1.5 Why is this topic important?

Chemistry teachers and professors are key actors to engaging a new generation around chemistry throughout Brazil and to embed a culture of green chemistry. Over the past five years, the Brazilian Green Chemistry School at the Federal University of Rio de Janeiro has been developing practical workshops in collaboration with professors and students and taken them to public schools and universities across the country.

Green chemistry education offers an enticing opportunity to develop a new approach for Brazil to embed low-cost, non-toxic chemistry experiments into Brazilian schools that are relevant to students' everyday lives and demonstrate how they can utilize science to help build a safer and more sustainable future for their communities and the planet.

However, recently it has been observed that several schools are closing their labs and stopping practical experiments because of rising costs and limited availability of the proper installations. This is a serious problem since lab work is an essential part of teaching chemistry and inspiring students.

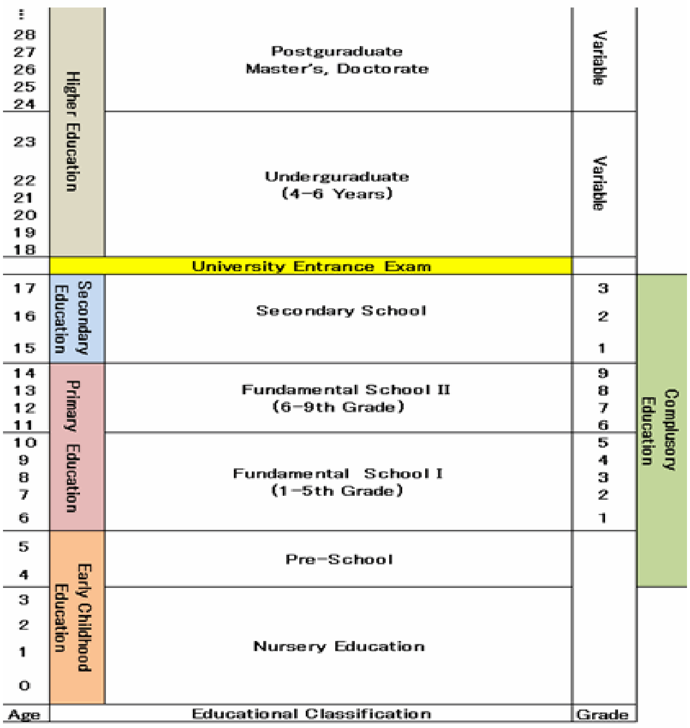
During the workshop “Green Chemistry Experiments for Remote Locations” international experts, local experts and school teachers were gathered to discuss and disseminate simple, low cost and locally relevant green chemistry experiments and activities that will engage students and ensure that a new generation of chemists is trained in green chemistry.

2. Chemistry education in Brazil

2.1 Overview of the education system

(Presented by Agnaldo Arroyo[1], Faculty of Education, University of São Paulo)

The Brazilian Educational System has two main levels: basic education and higher education. Basic education is mandatory and extends from kindergarten to high school students (4-17 year-old students). Higher Education is optional and includes undergraduate studies and post-graduate courses. In the public sphere, basic education is mainly a responsibility of local governments, with the federal government mainly responsible for Higher Education. There are, however, examples of public high schools linked to the federal government, as well as universities under the responsibility of state governments. In parallel to the public system, there are private schools at all levels of education.



Education System in Brazil

While chemistry concepts are presented to 8th and 9th graders (or even earlier), Chemistry as a school discipline appears only in high school curriculum. Although part of the schools have science laboratories, only a few actually use them for experimental practices – some schools use the laboratories on regular theoretical classes, and others do not use them at all.

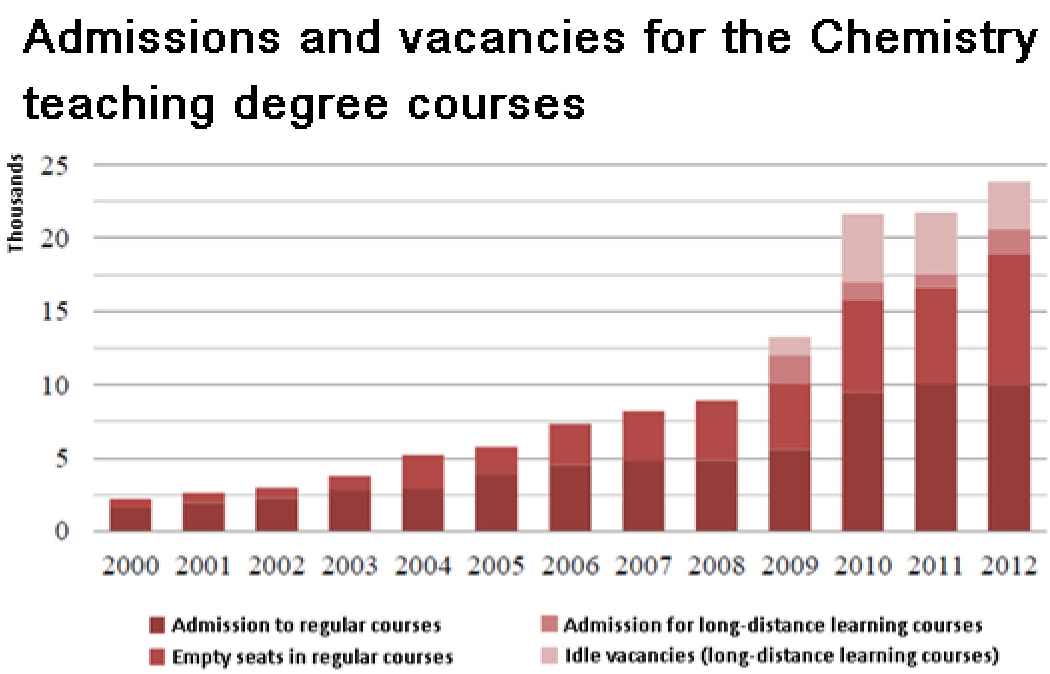
According to data from the Brazilian government, 99% of public schools and 98% of private schools have at least one computer. However, it is worth noting that those computers are often used for administrative activities and are not available for teachers and students. The

[1] Data can be found at https://www.scientiaplena.org.br/sp/article/view/2015 (PDF in Portuguese).

same is true for internet connection: 95% of public schools and 99% of private schools have it, but not all of them make the connection available to students and teachers. Added to this is the poor quality of connection: in 52% of public schools and in 28% of private schools the internet connection is lower than 2 Mbps.

Besides regular high school courses, there are also in Brazil technical schools that educate students for a specific career (i.e. chemistry, pharmacy, electronics, agribusiness, biotechnology and so on), known as “technical schools”. These are mostly public and the responsibility of the federal government. Their diploma is legally equivalent to one from high school – that is, it allows students to apply for admission to a university. Usually technical schools have better infrastructure than regular ones, and are a possible target group for experimental chemistry programs.

To become a chemistry teacher in Brazil, one has to take a chemistry undergraduate course and choose a teaching course (a course that includes didactics, teaching methodology and other specific disciplines) to get an educational license. In 2008, there were only 15 of these courses in Brazil. In 2014, there were 58. However, many of them have empty places, indicating that offering the courses is not enough; an even bigger challenge is to attract students to take those courses. In addition, school dropout is also a problem.



Brazilian students lack motivation to pursue chemistry education as a career. This can partly be explained by the low salaries and difficult working environment science teachers face around the country. Nevertheless, there is also the fact that many people had bad experiences with chemistry at school – “it is difficult”; “I don’t understand it”, “I can’t see it working” – and thus decide not to continue to study it for a career.

This suggests that any program or activity targeting green chemistry education must target teachers, as multipliers of knowledge, but also engage with the challenges that they face.

2.2 Examples of high school education experiences in cities and rural locations

2.1.1 Teaching chemistry in a federal high school in Rio de Janeiro

(Presented by Luis Carlos Gomes, Colégio Pedro II)

Luis Carlos Gomes is a chemistry teacher at Colégio Pedro II, a well-known and highly rated public school in Rio de Janeiro city. It is linked to the Brazilian Ministry of Education and has 179 years of history. Colégio Pedro II has 14 campuses (12 in the city of Rio de Janeiro and 2 in smaller cities near Rio) and around 13,000 students from elementary school to high school and on post-graduate courses (worth noticing, it does not have undergraduate courses).

Of the 14 campuses, 8 have high school students, all of which are equipped with a chemistry lab. Despite being privileged when it comes to infrastructure, Colégio Pedro II also faces challenges. For example, the school has plenty of laboratory glassware, but no reagents. Of the reagents it does have, 2 tons are out-of-date and there is no money to discard them properly – or to buy new ones. As teachers wait for the money, they try to keep the labs working by borrowing materials from other federal institutions.

As of 2017, Colégio Pedro II plans to have at least one laboratory activity per month for every high school class. To achieve that, the school is surveying campuses demands and financial resources. Gomes believes that it is crucial that Colégio Pedro II forms strong ties to the Brazilian Green Chemistry School, in order to bring sustainable practices and low cost materials into their teaching. He wants to begin this approach by presenting this white paper to the Head of Colégio Pedro II’s Chemistry Department and to the school’s Dean.

2.2.2 Chemistry education in Belém, Pará

(Presented by Jesus Brabo, Federal University of Pará)

Belém is the capital of Pará (a state in the north Brazil) and was founded in 1616. It is now home to 1.4 million inhabitants. The city is criss-crossed by rivers and includes 39 islands. Belém is a mixture of modern apartment blocks, forestry conservation areas and poor neighbourhoods – with wooden houses and no sanitation, contrasting with modern areas (see Attachment 1).

The city has 60,000 high school students, in 168 schools with each class having between 34 and 40 students each. All of these students require chemistry education and are a potential target for green chemistry activities. However, most classrooms are not properly equipped – they have school desks and white boards, but no books, no charts, no labs… (see Attachment 2)

In regular schools students go to school either in the morning or afternoon (i.e. there are two shifts of students per day) for a total of 20hours per week[2]. In these schools teachers report school dropout, student disinterest, and gaps of basic knowledge as the main difficulties. As many students come from low-income families, some of them end up leaving school to get a job. Others leave because school is "too hard". They have, for instance, math gaps that make learning chemistry a lot harder. Teachers report extra-curricular activities, such as visits to local universities and industries, as useful tools to improve chemistry learning.

Alongside the regular schools, Belém has three new public "integral" (full time) schools, where students go to school for the whole day (40 hours/week) with classroom teaching augmented by workshops, laboratory practices and other activities. Teachers that participated in the GII workshop criticized the fact that these schools often focus on preparing students for the ENEM (Brazilian national high school evaluation) rather than focusing on a broader education. However, they also mentioned a project called "Química das sensações" (Chemistry of the sensations) where students learn to produce soaps, lotions, disinfectants, perfumes, candies and other products – an interdisciplinary program with a clear focus on entrepreneurship.

These "integral" schools, according to the teachers, have good results, and most students are able to join universities afterwards. Nevertheless, they also face challenges: lack of

[2] In Brazil, during basic education, students are required to be inside the classroom for at least 800 hours per year (there are 200 school days/year). Usually public schools have two shifts of students (morning/afternoon) from Monday to Friday.

didactic and financial resources is one of them. A teacher exemplified this by explaining that, although her school was supposed to offer lunch for the students so they can stay all day, it often does not have money to afford it, so sometimes students have to go home by midday.

A teacher from the state of Amazonas, also in Northern Brazil, reported that “integral” schools in their region have good infrastructure but lack qualified human resources. And their results are not better than regular schools outputs: since students go to school full time, they do not have time to take extra courses to prepare themselves for the ENEM[3].

Prof. Brabo added Belém is building new “integral” schools with recently established infrastructure standards (including classrooms for 30 students each, laboratories etc.) which will be open by the start of the 2017 school year. One of the main challenges will be to establish guidelines and legislation on the special activities those schools will have to offer (nowadays each school makes its own decisions about this).

The teachers working environment also appeared as a major issue when it comes to improving education in Brazil. Low salaries and fragile working contracts were mentioned. Also, in regular schools, teachers are paid for the time spent in classrooms, but not for the hours they spend outside classrooms preparing activities, tests and so on. Additionally, teachers are not interested in taking post-graduate courses because that would not increase their salaries so there is little opportunity or incentive to teachers to continue their own professional development.

According to Brabo, the Federal Institute of Pará, with 1,000 students, offers the best chemistry education experience in Belém. It offers technical high school education, regular high school education and teaching education. Infrastructure is satisfactory and there are 17 chemistry teachers, most of whom hold masters or PhD degrees.

2.2.3 Brazilian Chemistry Olympiads

(Presented by Luis Carlos Gomes, Colégio Pedro II)

For the past 21 years, Brazil has held national and local editions of Chemistry Olympics. The event involves public and private high schools throughout the country and in 2016 had

[3] The ENEM started in 1998 as a way of evaluating Brazilian high schools. Since then, some universities began using students’ individual ENEM scores to select undergraduate candidates. Later all federal universities in Brazil – and part of state universities and private ones – started using ENEM scores to rank candidates. That led some students to take extra preparatory courses outside school in order to improve their performance in the ENEM.

340,000 participants. The Brazilian Chemistry Olympics (BCO) have been playing an important role on improving chemistry education. To engage students, the BCO approach a special topic each year, combining with the National Science & Technology Week (in 2016, the theme was “Science feeding Brazil”).

Many schools have altered their chemistry curriculum in order to prepare their students to participate on the Olympics and achieve high scores in the exams. Other added extra chemistry classes, given by preservice chemistry teachers (undergraduate chemistry students received a scholarship to take part on the project).

Consequently, BCO have brought thousands of high school students more close to chemistry and gathered interested teachers and school principals together with BCO’s organizational team. Since 2015, the Olympics include a practical test, which has been an incentive to experimental practices in the schools, following the principles of green chemistry, even in schools that are not equipped with a laboratory. Green chemistry is also an important topic of the theoretical tests, teasing an important shift on chemistry education in high schools.

The BCO team also offers special Olympics for younger students and participates on the organization of the Brazilian Science Olympics, which cover both chemistry and physics topics. Besides the National Olympics, each state organizes local editions. Brazilian students also participate on the International Chemistry Olympics with good results – last year, the four participants brought home silver or bronze medals, putting Brazil on the 17th position in the ranking of 80 participating countries.

2.2.4 Chemistry education in different contexts

(Outputs from workgroup discussions)

	Audience characteristics	Available resources	Types of activities	Key topics	Other ideas
High schools in urban areas	Students (around 14-20 years old), group sizes are about 25-30. Realities vary enormously between Brazilian regions and states. Private and public schools also have huge differences.	Depending on the school: labs, alternative materials, internet, software, apps, financial resources.	Short videos (10-15 minutes) + discussion; visits to industries; experiments; participation on the Chemistry Olympics.	Sustainability; Brazilian new national curricular basis (in development).	Schools need to make an effort to include green chemistry concepts in their curriculum. It would be useful to have a network of teachers.
High schools in rural areas	Sons and daughters of farmers and rural workers. Three main groups: regular high school students (14-17 years), youth and adult education groups (18-70 years old), “educação de campo” (education in small rural communities, riverine groups, indigenous groups etc / 19-70 years old). They need specific curricular proposals.	Vegetable pigments (urucum, jenipapo etc), fish, flour, milk (traditional processes for producing flours, cheese etc.), different kinds of soil, vegetable oil extraction, medicinal plants.	Extracting jenipapo pigment (1,5 hour); producing cassava derivatives (3 days); artisanal cheese production (2 hours). Those activities could be taken to non-formal education spaces.	Carbon chains; organic functions; chemical reactions; biochemistry; Chemical calculations (stoichiometry).	Andiroba oil extraction by centrifugation, using a washing machine (that homemade process allows us to extract 95% of the total oil).
Universities	Students start undergraduate courses at the age 17-19. Classes have 35-40 students each and the courses last about 4-6 years. Dropout is an issue. Another challenge is the students’ lack of basic knowledge (math, reading, science concepts).	There is a shortage of all kinds of resources – material, human, educational. Teaching degree’ professors have poor education.	Teaching activities in non-formal educational spaces, video lessons, green chemistry experiments. They all need financial investments.	Biodiversity, water, soil (mining), air pollution, sanitation, medicinal plants as inspiration to teaching topics such as organic chemistry, geology, biotechnology.	Interactive teaching networks in partnership with private companies, schools, universities, and rural communities. Engage teachers in alternative activities (many remain passive in relation to the problems they face).
Public engagement activities	Public displaying fear or distrust; gender perspective; all ages and all backgrounds; 2 main audiences: those already attending events/museums and people not engaged (the last one should be the main target).	Annual Science & Technology Week; science museums (e.g. Museum of Tomorrow in Rio de Janeiro); YouTube; tax break for companies who do public events; local resources and resources already available; UNDP networks	Chemistry festival, night at museums, chemistry and art, books/beer/food festivals, science communication books and magazines, posters about chemistry in daily life, Amazon.com pilot program.	Link to relatable topics such as food, art, diapers, cosmetics, beer, wine etc. Safe and simple experiments.	Ahow chemistry is everywhere. Activities must be exciting and related to peoples’ lives. A possibility is to translate already available materials. It would be useful to create a national network of green chemistry.
Online activities	High schools and universities (15+ years old).	Regional products and processes; multimedia equipment; basic chemistry lab equipment.	Activities would vary according to the targeted product or process but might include video making, websites, and events to exchange experiences.	Fertilizers, pollution, pottery (and many others).	Important to value traditional knowledge and to stimulate diversity. Also include green chemistry concepts in multimedia production guidelines.
Working with industries	Primary, secondary, tertiary and industrial levels.	Fruits (orange peel), coffee beans.	Practical experiments using local reagents and materials; accompanying videos of key techniques.	Wealth from waste, green chemistry principles, education from produce/ waste.	Integrating green chemistry education with industry could be solution to lack of reagents and other materials. Need to form industry professionals so they can take green chemistry concepts into their companies.

3. Teaching Green Chemistry in Remote Locations

3.1 Teaching green chemistry in the Amazon

(Presented by Celia Maria Serrão Eleutério, State University of Amazonas)

Traditional knowledge must be taken into account: was the take home message of Celia Eleutério's presentation. She is a professor at the State University of Amazonas and has been working in this area for the past 10 years. She believes bringing traditional knowledge into academia is a good way to rescue and value a piece of Brazilian culture that is disappearing fast.

On the other hand, it is also a way to teach chemistry and to experiment with local, low cost, easy to find materials. According to Eleutério, there were investments in chemistry education in the Amazon region in the past, but now schools and universities lack resources and materials, turning experimentation into an unreachable practice.

Knowledge from indigenous, riverine, "quilombolas" and "caboclo"[4] communities can contribute to the development of simple experiments that can be used to teach chemistry. In addition, chemistry research from universities can help those traditional communities to find new ways of developing their activities. As an example, Eleutério mentioned a tribe that used ashes from a very specific tree to make pottery. As the tree is under extinction risk, so is the pottery production – but chemistry can help to find a new material for them to use.

Bringing people from the small communities into the university is key to this type of activity. Students can help in this mission: they can invite their parents or grandparents, people from their neighborhoods, and so on, to events. This way, they start from a concrete theme (i.e. pottery) to discuss chemistry concepts. Besides pottery production, other traditions that can be brought into the university are cassava derivatives and artisanal cheese making.

Eleutério highlights the potential of this kind of activity to be used not only in universities, but also in high schools. She also highlighted that local knowledge related activities are interdisciplinary – looking at a traditional practice, students can learn about history, biology, geography, physics, math…

[4] The "quilombolas" are descendants of slaves that ran away from their lords, stablishing communities in the forest. The "caboclos" are descendants of mixed indigenous-white people families.

3.2 Teaching green chemistry in the islands of Pará

(Presented by Carlos Alencar, Escola Bosque / Funbosque)

Escola do Bosque[5] is a school system spread over 4 islands in the Pará state: Outeiro (headquarter), Cotijuba (3 schools), Jutuba, and Paquetá (see Attachment 3). They have students from elementary levels (in the small islands) to high school (only in Outeiro). The schools' infrastructure is quite unusual: they have separate labs for each school discipline, there is no air-conditioning (the schools' architecture favors air circulation), and only the headquarters have electric energy (the other buildings rely on diesel fuel).

Escola do Bosque has currently 4 classes of high school students with a maximum of 35 students per classroom. Rooms are given names of local animal species or myths and are connected by green trails.

Teachers have a workload of 30-40 hours per week, of which only a small part (for some teachers, only one hour per week) is spent in traditional classrooms. They must develop environmental-focused projects with the students and all teachers have one day-off each week to study from home.

As financial resources (from Belém's city government) are scarce, students and teachers often take grocery, waste and other materials to the school and use them in laboratory practices. The teachers and students are extremely innovative, if they do not have proper equipment, there is no problem: teachers and students are always willing to build their own special ones, such as the example of a heater made from an iron. (see Attachment 4)

Escola do Bosque also aims to establish a close relationship with the local communities and has projects to ensure this. One example is a garbage collection effort held on the islands during the tourist season in July. Students also visit many local and regional institutions, such as universities and companies.

3.3 Existing green chemistry experiments

Attendees from the UK, USA and Brazil shared existing green chemistry experiments relevant or that could be modified for the Brazilian context or low-resource settings.

[5] More information on http://www.funbosque.com.br/

3.3.1 Ken Doxsee, University of Oregon (USA and around the world)

Green chemistry practices started at the universities as a way of reducing costs. Only after that people realize how important is to educate using green chemistry concepts. For years Doxsee has travelled the world promoting green chemistry experiments with low cost and easy to find resources. To the workshop, he brought two experiments.

The first one followed the lead of chemical educator, Professor Muhamed Hugerat, of the Arab Academic College for Education in Haifa, Israel. It explored adaptations of one of the simplest and best-known chemical processes, the electrolysis of water. Electrolysis, the use of electricity to convert water into its elemental components, hydrogen (H2) and oxygen (O2), also results in the creation of acid (H+) and base (OH-). Their creation can be visualized by including an "indicator" that changes color in response to acidic and basic conditions.

Many plant extracts undergo such changes. The experiment in the workshop used dilute hibiscus tea (but could have used açaí, for example). OH- formation was simultaneously observed by adding olive oil, which underwent a chemical reaction with OH- to generate soap. Addition of table salt (NaCl) to the water undergoing electrolysis caused the formation of chlorine (Cl2) as well as O2. Cl2 formation was observed by again adding olive oil, which reacts with Cl2 to create "polyhalogenated vegetable oil," forming a margarine-like solid.

All materials used in the experiment can be found everywhere or can be replaced by local ones.

3.3.2 Mollie Enright, Beyond Benign (USA)

Beyond Benign introduced four high school level activities, three of which exclusively use items found in a typical grocery store. These activities have been designed to teach core chemistry concepts that are built into the curriculum, whilst using alternative materials that are safer, work just as well, and cost less than traditional materials. One of the activities showcased a double displacement reaction, which traditionally uses materials with negative effects on health and the environment, containing lead compounds or chromate compounds to produce colorful precipitates. As an alternative, Beyond Benign demonstrated that the same reaction can be performed using minimally hazardous materials, calcium chloride and sodium carbonate, that result in a precipitate of calcium chloride, commonly known as chalk, and aqueous sodium chloride, which can be safely disposed of down the drain. The other activities included an exothermic reaction using catalase in beef liver and hydrogen peroxide and two equilibrium demonstrations using grocery store items like tea, vinegar, ammonia, and iodine and starch. Using safer materials, especially grocery store items, decreases cost of materials compared to ordering through a chemical supplier, decreases risk in the classroom by decreasing hazards associated with the materials, and decreases the cost and environmental impact of disposal. Beyond Benign describes these and other experiments in this link. Materials presented during the workshop are available on Google Drive.

3.3.3 Glenn Hurst, University of York (UK)

As an alternative to the traditional PVA-borax gelation, Glenn Hurst presented a green system: alginate-calcium chloride. Rheology measurements can be made simply by pouring the alginate solution into a measuring cylinder, adding a ball bearing and timing how long the ball bearing will take to fall a certain distance (measured via gradations on the measuring cylinder). This can then be converted into a speed. The viscosity of the alginate solution as a function of temperature can be investigated together with the behavior of the gel as a function of calcium chloride addition. Degelation can be studied as a function of trisodium citrate addition (paper to be imminently published in *Journal of Chemical Education*). If PVA is used, the gelation can be observed using sodium trimetaphosphate.

Other experiments used at the University of York include: an easy, cheap, green method to make glue from milk; a facile method to plastic packaging from starch (potatoes/cassava) and a method for determining the pH of unknown solutions using red cabbage as an indicator (all instructions on GoogleDrive).

Other experiments that were suggested include: using bananas to make biodegradable sanitary pads; aromatic compounds from cashew nuts; extracting pectin from citrus peels (boil with citric acid); and working with local industry to source reagents/local materials for green chemistry experiments.

3.3.4 Rafaela Nascimento, Federal University of Rio de Janeiro (Brazil)

Two experiments about carbon dioxide were shown. The first one was a demonstration with the “pH of the Planet” kit (developed for the Global Experiment for the International Year of Chemistry) – using test tubes containing an acid solution in one, and a basic solution in the other, they both change colours with the indicator solution. The second experiment uses a small PET bottle containing vinegar and a birthday balloon attached to the bottle mouth containing baking soda. When the contents of the balloon are added to the bottle, the balloon begins to inflate, showing the formation of carbon dioxide.

A third experiment was to recycle Styrofoam using limonene. A couple of drops of limonene are added to a piece of Styrofoam until the Styrofoam "disappears". Fourth, an experiment from a partnership with Oxitenio was demonstrated, showing a lotion that that have developed which is formed by mixing with water rather than a more toxic organic solvent.

Lastly, a molecular gastronomy experiment was performed. Milk was placed in a disposable cup with coffee spheres formed from a mixture of sweetened coffee and sodium alginate dropped into a solution of calcium chloride. The person drinks the mixture and when the coffee ball pops, the latte is instantly formed inside the mouth. The experiment helps to explain how algae is the lung of the planet, due to its great capacity to absorb CO_2 from the atmosphere. It also allows speak of natural polymers, since the alginate used to form the spheres is obtained from the algae.

3.4 Sources of information for green chemistry activities

- Beyond Benign resources in Green Chemistry - http://www.beyondbenign.us/home/K12education/highschool.html

- Greener Education Materials from University of Oregon - http://greenchem.uoregon.edu/gems.html

- G2C2 global network of green chemistry centres - http://g2c2.greenchemistrynetwork.org/

4. Key Challenges

Following the in-depth discussions about the current status of chemistry education in Brazil it was agreed that aiming to embed green chemistry in education in Brazil offered the opportunity to overcome many challenges faced in teaching chemistry. This would be achieved by offering low cost and safe experiments that could be applied in settings with little laboratory equipment, whilst at the same time teaching relevant chemistry concepts utilizing topics relevant to students' lives. The aim would be to develop public knowledge and students who would excel at innovating to develop new technologies and processes in industry and research needed for a more sustainable future.

During the workshop, we identified a range of key challenges to the spread green chemistry education throughout Brazil. These were:

- **Creating an adaptable curriculum that enable educators to utilize activities relevant to local contexts and the knowledge of students:** it's not enough to have a series of experiments or activities – they need to be adaptable to the different locations in Brazil. As the culture and context varies from urban to rural and indigenous communities, it will be vital to develop activities and curriculum that are relevant to these different realities, working with students to utilize their knowledge and culture.
- **Creating a community of practice for green chemistry education.** There are already lots of fantastic activities and practices throughout Brazil, but they are not connected altogether as a group. Currently, educators, particularly those with an interest in sustainable chemistry, are dispersed across the country with little support. A community of practice that can provide peer-support and mentorship for educators that want to test and implement new approaches is needed.
- **Ensuring that green chemistry is integrated into the training of chemistry teachers**. National curriculum is now supposed to include green chemistry, but how that will be done is still unclear. Engaged green chemistry specialists might play a key role on implementing this.
- **Improving the working environment, infrastructure and access to materials and resources for teachers**. Educators need access to experiments, equipment, didactic resources, infrastructure and the working environment that supports them to implement green chemistry approaches.

5. Next Steps

Participants were asked to suggest solutions to the identified challenges, thinking of short term, midterm and long term proposals. Similar proposals were divided into 4 main groups and proponents were split into those to discuss their suggestions. The following next steps were defined.

a) Teaching degree education

Opportunity: Brazil is currently preparing a new version of its national curriculum standards. This will include green chemistry topics, however, the approach to teaching this content is still not defined and teachers may not be properly prepared to teach them. This offers an opportunity to ensure that teacher training is properly developed to ensure that teachers are confident and able to teach green chemistry. In this context, green chemistry should be viewed as an overarching philosophy and relevant across the chemistry curriculum. Green chemistry ambassadors can provide their view, concerns and proposed solutions to the non-expert leaders (i.e. curriculum designers).

Practical proposal: National workshop on green chemistry education in high schools. Participants would be university professors, teachers and also Ministry of Education representatives, university deans and other stakeholders. International participants could be invited to help to highlight the importance of the initiative. By the end of the workshop, a committee would be established to organize a proposal of how to include green chemistry in teachers' education.

When? August 2017, together with the 15th Brazilian Symposium of Chemistry Education (SIMPEQUI), which theme is “traditional knowledge and science – a dialog in chemistry education”.

Action: Célia Serrão and Pedro Campelo to act as coordinators for organising this meeting in 2017.

b) Online platform

Opportunity: An ideal method of sharing green education materials and to promote green chemistry is via a website and online resources. The Brazilian Green Chemistry School currently has a website (quimicaverde.eq.ufrj.br), but it is not very well known. An approach is needed to reach a wider audience.

Practical proposal: Create a new collaborative website with a friendly URL (quimicaverde.br) and start working on social media (Facebook, Instagram, Twitter) to establish a virtual community of people who work with or are interested in learning about green chemistry across Brazil. The website will target teachers and students from different educational levels. Content (experiments, texts, videos) will be divided into different levels (i.e. undergraduates, high school students, elementary etc) similar to the Beyond Benign website. The content will include new material developed in Brazil and material translated into Portuguese from other sources. Topics will include: what is green chemistry, green chemistry concepts and principles, green chemistry in the school curriculum, green chemistry in our daily lives, experiments and other practical activities, didactic resources. The website would also have a forum and an online form to find collaborators.

When? ASAP dependent on financial resources to build and maintain website.

Action: Rafaela Nascimento will look to find additional volunteers to manage social media and to review activities submitted for inclusion in the resource library. Luis Carlos Gomes will explore how to approach green chemistry topics relevant to the national curricular standards. An initial website was set-up to promote the project (quimicaverdebrasil.wordpress.com). A Facebook group for educators (“Educação em Química Verde no Brasil”) was created and has already with 100+ members. The group is working with Beyond Benign to select and translate materials.

c) Green chemistry ambassadors

Opportunity: An emergent network of interested and engaged chemistry educators distributed across Brazil was identified at the workshop who could act as ambassadors and mentors to spread the message around Brazil and connect groups from different regions.

Practical proposal: Develop a network of Green Chemistry Ambassadors across all the states of Brazil starting with 6-8 key states in the North, North-East, South and South-East of Brazil. Initial ambassadors will be identified using existing contacts and networks and will be invited to an initial one-day workshop and meeting before the SIMPEQUI chemistry education conference in August. This workshop will enable educators to develop a shared understanding of green chemistry and develop initial objectives for the network. Prior to the meeting the ambassadors will conduct a survey (with teachers, with students, with stakeholders) to identify local needs. The ambassadors in the network will support the other activities identified at the GII workshop and will organise training workshop and events at a local, regional and national level to support the implementation of green chemistry topics.

When? Ambassadors recruited by August 2017. One-day workshop and meeting before the SIMPEQUI chemistry education conference in August 2017.

Action: Frederico Schoene and Thiago Parmesano will coordinate the activities. The group is organizing a course on Teaching Green Chemistry for high school teachers in March 2017.

d) Online courses

Opportunity: Brazil is a large country with a dispersed population but with growing connection to the internet. Online materials offer an ideal opportunity to reach a wider audience, both students and teachers, particularly in remote communities.

Practical proposal: The online courses would be teacher or student-focused. They would be free to users (perhaps university sponsored?), flexible, and downloadable, so people that do not have full-time internet connection can access them as well. They will address regional needs and relate to daily activities (i.e. cooking). Multimedia resources (video), gamification and interactivity would be beneficial. It would also be useful to have the courses in Portuguese/Spanish/English. Courses aimed at teachers can include developing materials for classroom use – lessons would then be shared with a larger education community, connecting teachers from different parts of Brazil.

When? N/A

Action: University of York (Glenn Hurst) will: Share their portfolio of green experiments for use in secondary schools and work in partnership to construct new experiments for remote locations, making use of local resources; complete the children's book on green chemistry and associated teacher pack while exploring the potential for this to be translated into Spanish/Portuguese; consider how we can develop a blended learning resource for the secondary level – perhaps a similar platform to our Chem21 platform (http://learning.chem21.eu); explore the potential of working with schools and local industry. Beyond Benign will work with the team in Brazil to share their online teacher courses and support the development of locally-relevant materials.

e) Other ideas

- Apply didactic material projects to the NOVA SALIC platform grants.
- Connections with the chemical industry.
- Partnerships with UNESCO and UNICEF.
- Use green chemistry as an innovative pedagogy to teach chemistry.

- Asking for ACS support to laureate best posters presented at universities' chemistry weeks.
- Science museum exhibitions
- Develop more green chemistry experiments with low cost materials.
- Green chemistry platform at the PEOI (Professional Education Organization International).
- Organizing UNV-Online Volunteer Service (www.onlinevolunteering.org/en) calls to attract volunteers that can help with translation, design and event organization.

6. Support Needed

In order to bring these ideas into practices, the group need support and engagement from different groups.

Funding is a major need, including financing for:

- Sponsorship of policy and green chemistry ambassadors workshop in August 2017
- Website development
- Training courses
- Setting-up laboratories

Other needs are translation of teaching materials into Portuguese, support for hosting events, materials (such as lab equipment and materials for teachers), and media and IT skills for the development of digital and printed materials.

Attachment 1: Pictures of Belém, Pará, Brazil

Historical centre

Modern areas with tall buildings and poor neighborhoods above

Poor neighborhood in Belém

Attachment 2: Public high schools in Belém - infrastructure

External area

Typical classroom

Multidisciplinary lab in a “integral” school

New lab at a “integral” school that shall start activities in 2017

Attachment 3: Different buildings of the Escola do Bosque


Sabor de M


FORD

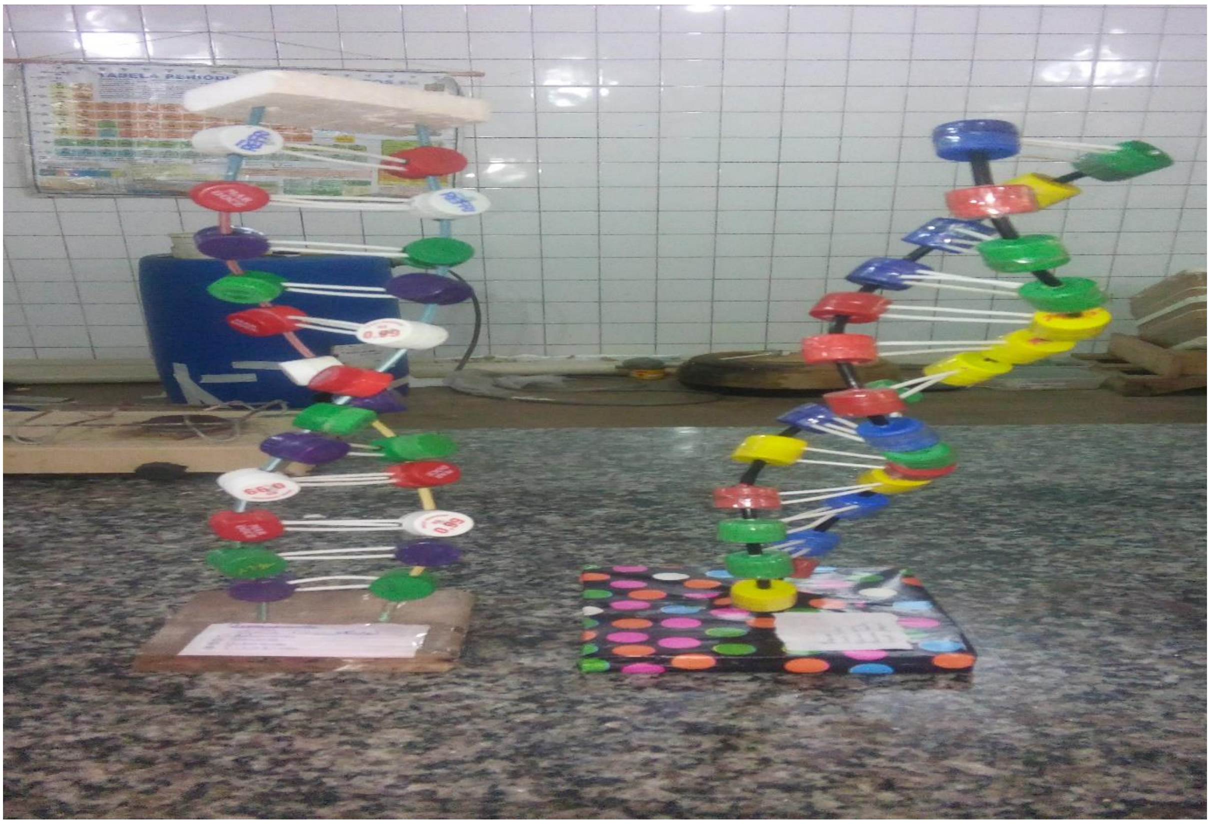
Attachment 4: Equipment made with day-to-day materials

Heater

Vacuum cleaner

Fume hood

Distillation equipment



DNA model

Humidity measurement apparatus