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Incorporating Sustainability in Higher Chemistry Education in Indonesia through Green Chemistry: Inspirations by Inquiring the Practice in a German University

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Abstract
Green chemistry is suggested as an important guide to allow the practice of chemistry to become more sustainable. In this study, a chemistry department at a German university is analyzed by an outside view to how it integrates the philosophy of green chemistry into its research and teaching practices to inform higher education institutions in Indonesia on how this issue could be approached. The study reveals that the level of understanding of green chemistry is largely varying among different stakeholders, however its principles are well integrated in both research and teaching. In addition, it became clear that today modern chemistry departments should operate a broader approach towards sustainability than just practicing green chemistry in laboratory practices. The vision is to highlight the importance of green chemistry and other corresponding practices to support education for sustainable development (ESD) in a broad sense. The integration of green chemistry to support the implementation of ESD in higher education can only be achieved by strong commitments from all groups involved, namely the head and administration of the department, researchers, and teachers. Although not all aspects that were observed during this study are suitable to be applied in the Indonesian context, some implications can be derived for reform in Indonesian higher chemistry education.

Keywords
Higher education reform, education for sustainable development, knowledge transfer, green chemistry

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Introduction
The years of 2005 to 2014 were announced by the United Nations as the Decade of Education Sustainable Development (DESD). Governments from all over the world as well as other stakeholders were called to incorporate the values related to sustainable development into every one of their educational programs (UNESCO, 2011). There are many different routes to sustainability which were mentioned in the Agenda 21, the official document of the 1992 Earth summit, and education is one of these routes (UNCED, 1992). Of course, while education in itself cannot achieve sustainable development, learning about sustainability is suggested to be a key aspect to achieve this goal (UNESCO, 2016).

With the threat of global climate change, environmental pollution and decreasing resources, a call for a movement toward more sustainable practices emerged. It is imperative that we, as a global society, have to change the way we live and strive to be more aware of our personal actions (Klingshirn & Spessard, 2009). All over the world we see developmental gaps occurring among different countries. However, with every country's government recognizing the significance of science and technology for national development, the role of chemistry and chemistry education for sustainability justifies itself to be of importance (Bradley, 2005; Burmeister & Eilks, 2013). Therefore, chemistry education should have a special responsibility to contribute to an education for sustainability (Sjöström, Rauch & Eilks, 2014; Burmeister, Rauch & Eilks, 2013) and at the same time helps chemistry education to strengthen its character as relevant education for the future generation (Stuckey, Hofstein, Mamlok-Naaman & Eilks, 2013).

While the development in the field of chemistry during the last two centuries was full of innovation and discovery, the impacts of what us as scientists did to the environment was not always fully considered (Anastas & Beach, 2009). The field of green chemistry, whose theory and principles were introduced by Anastas and Warner in 1998, can play an integral role in moving chemistry and its related industry and products towards a more positive and sustainable direction (Klingshirn & Spessard, 2009). This also has to incorporate reforms in chemistry education as the starting point (Burmeister et al., 2012). Thus, educating the next generation of chemists is part of the fundamental framework of green chemistry as a step forward towards more sustainability (Anastas & Beach, 2009).

In Indonesia, the ESD campaign was started by the launching the DESD in 2005, as collaboration between the Ministries of Education and Environment. The collaboration was expected to develop strategies for implementing ESD on all educational levels and across disciplines. This was followed by the appointment of the Rector of the Universitas Gadjah Mada (UGM), one of the oldest universities in Indonesia, as the National Coordinator for the implementation of ESD (UNESCO, 2011).

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The ESD national implementation strategies aim to:

- increase access and opportunities for quality basic education, especially for poor and disadvantaged students;
- improve the quality of basic education services and facilitate the ability and potential of the community to ensure an efficient early childhood education;
- improve capacity-building at local and community levels through school-based management and community participation; and,
- improve the professionalism and accountability of educational institutions based on knowledge, skills, experience, attitudes and values derived from both national and global standards (UNESCO, 2011, p. 39).

New curricula were developed to incorporate ESD into the educational system, especially at the primary and secondary levels. The curricula allow teachers to incorporate a different set of teaching materials and strategies in their teaching based on the standards defined by the Ministry of Education. The implementation of ESD in the curriculum was thus possible, although the practices still varied greatly from school to school, or university to university. In schools, the implementation was done mainly through environmental based education and carried out in certain schools called "model schools", and the materials were developed based on projects and grants, such as through the cooperation with the UNESCO. So, the implementation of ESD included community based education both as government guided programs and programs involving non-government organizations (NGOs) (Ardiansyah, 2014).

Nonetheless, it is believed there is still some confusion in regard to the difference between ESD and forms of traditional environmental education in Indonesia, both for the secondary and tertiary educational levels (Ardiansyah, 2014). While traditional environmental education, which had been initiated in 1990s, can be considered to be in the core of ESD initiatives in Indonesia, the inclusion of socio-economic and cultural aspects of ESD did not receive the same emphasis in the curriculum. Topics related to environmental issues were introduced in the school curriculum, including chemistry. However, other than the inclusion of topics from environmental chemistry, the broader role of chemistry as a part of the implementation of sustainability has not been yet specified. ESD is often confused as mainly environmental based education, the term environmental chemistry and green chemistry are often confused and used interchangeably. This highlights the importance of incorporating a broader view on green chemistry and sustainability into chemistry education in Indonesia for promoting thorough ESD and this needs to be accompanied by corresponding teacher education and continuous professional development. This is apparently not specific to Indonesia, as suggested by Andraos and Dicks (2012). Thus, it is likely that the principles of green chemistry and its relation to sustainable development within the ecological, economic and societal domains (Burmeister et al., 2012) are still not widely known or taught to tertiary level students, let alone the general public. A number of studies in Germany also described shortages in the corresponding knowledge base among tertiary chemistry students (Burmeister & Eilks, 2013) as well as chemistry teachers (Burmeister, Schmidt-Jacob & Eilks, 2013).

In general, attempt needs to be made at generating ideas for the integration of green chemistry and sustainability into chemistry education to support the implementation of ESD at university level and in teacher education in Indonesia. As a starting point however, in this part of the research we start with a focus on learning from the experience in another country, in this case Germany. The implementation of ESD at higher education in chemistry in Indonesia was initiated by UGM through the cooperation with the German Academic Exchange Service (DAAD) over a series of green chemistry research project and a master's dual degree program in chemistry, which puts Germany as one of the countries with a central role in the development of green chemistry education in Indonesia. A notable influence is the Nachhaltiges Organisches Praktikum (NOP = Sustainable Organic Chemistry Lab Course) project developed through the cooperation of a number of universities in Germany, among them the University of Bremen. The NOP project (NOP, 2013) provides detailed instructions for a number of organic chemistry laboratory works that have been adapted to include the principles of green chemistry. So far, the lab course is available online and has already been translated to many different languages, including Indonesian. For this reason, we decided to conduct a site visit to Germany, and more specifically the University of Bremen, to learn more about how green chemistry is implemented and how the teaching in chemistry at the University of Bremen is related with ESD.

Method and sample

To obtain a broad overview about how the fields of green chemistry and sustainability are put into practice, interviews with professors, teaching and research staff, technical staff as well students were conducted. We conducted 13 semi-structured interviews of about 30 minutes each and two additional interviews with lecturers from UGM, Indonesia, to allow us to interprete some of the ideas that were obtained from the interviews in Germany. The sampling was done purposively to obtain most comprehensive information, and an overview of the participants is displayed in **Table 1**. The interviews were recorded and later transcribed. The results were qualitatively analyzed using an inductive approach (Southampton School of Education, 2012), by first iteratively assigning different codes to the interview transcript part by part. The codes were later grouped and different sub-themes were generated. Later, the sub-themes were reduced and clustered into major themes. Examples of the interview questions and answers can be seen in **Table 2**.

Table 1. Overview of the interviewees from the University of Bremen

List of interviewees	*n*
Professors	5
Teaching and research staff	4
Technical staff	1
Master's students	3

Table 2. Examples of interview questions and answers

Questions	*Answers*
How familiar are you with the term green chemistry?	**Student 1**: I think the first time I heard about this term was here on a didactics seminar part of the chemistry education studies. I think during the time when I only studied pure chemistry courses, I did not hear [about] the term or any issue related to the concept. I think the only thing I heard about was when it came to using less [chemicals] and maybe less hazardous materials, but it was justified because of the costs, and not related to the effects on the environment. **Student 2**: I think the first time I learned was back in school, but it was just said "be careful of the chemicals, don't spend too much because they are expensive," and that it was somehow bad for the environment … I think that was the first time I learned it, or maybe heard of it, not learned it. I think in my full chemistry course, we never heard about it.
How are the principles of green chemistry being implemented in your research/laboratories/institution?	**Professor 1**: …we do not have any course in green chemistry, but we know the 12 principles by heart. We decide which of them is of any interest for us as engineers, interest in terms of how they are important in controlling what we are doing. **Professor 2**: Our researchers focus on designing better products in terms of lower toxicity and higher sustainability in corporation with companies actually, … We give lectures in environmental science and in product engineering, chemistry for production engineers, and there is always a part of education in green chemistry. So we are being aware about the responsibility, … that you somehow are also responsible for the chemicals that you produce, that you're aware that those chemicals have effects. And in all lab courses, for example where we have practical work, safety is very important at the beginning. So before we start any experiment, we inform about the safety measures that we operate in the lab...
How is the waste being managed in relation to the principles of green chemistry?	**Academic staff**: [Waste] treatment centers in Germany are a very special topics, because it is regulated by the regulations of waste management, and [it] is clearly stated what has to be done with waste in general. When I see the principles of green chemistry, half of them are covered by the regulation of our waste management, and the other half are covered by the regulation on work safety. So it is in fact very easy to make green chemistry because you have to reduce, produce less compounds, [use] as few as possible, using less steps, less dangerous compounds, because it is demanded by the regulation on work safety.

Findings and discussion

During our interviews, each participant highlighted different aspects of green chemistry and sustainability, and thus allowed us to obtain comprehensive information of how the principles of green chemistry were implemented. Generally, the heterogeneity among the groups was as similar as across the groups. In analyzing the data from our interviews, the following themes emerged: (1) implementation of green chemistry in courses and laboratory work, (2) use of green chemistry principles in research, and (3) environmental and chemical waste management. We will elaborate these key themes in the following narratives, followed by the description of some of the challenges and opportunities for the implementation of green chemistry in higher education in Indonesia.

Green chemistry in courses and laboratory work

Chemistry and chemistry education courses in the University of Bremen are mainly given in the Department of Biology and Chemistry. We found that in the Department of Biology and Chemistry in general there is no specific introduction to the principles of green chemistry for chemistry students enrolled in a program to be chemists at the undergraduate level, neither in theoretical, nor in practical courses. For student majoring in chemistry education to become chemistry teachers, however, green chemistry and ESD are introduced explicitly in a 6-weeks course module as part of a course on chemistry education. The course module is specifically dedicated to sustainability and green chemistry and is taught using a variety of different methods, such as lectures, cooperative learning, games, and presentations (Burmeister & Eilks, 2013).

All student teachers that were interviewed from the chemistry teacher education program, were familiar with green chemistry and sustainability as theoretical-based terms. All of them were aware about the strong regulations for waste disposal that are thoroughly applied during all laboratory activities. They all recognized that some of the principles of a more sustainable chemistry were already integrated in their laboratory activities, like small-scale chemistry experiments and replacement of environmentally dangerous chemicals. An explicit contention to the student teachers is done in a lab course where essential components of the Student-Active-Learning-in-Science (SALiS; Kapanadze & Eilks, 2014) project having been implemented, like lessons how to introduce lab safety and how microscale techniques and low-cost-equipment can help to reduce costs, chemical consumption, and risks. Even more explicit is the contention with green chemistry in a second-year chemistry education seminar (Burmeister & Eilks, 2013). In the 6-weeks course module, the student teachers explicitly learn the principles of green chemistry in a WebQuest and how green chemistry is operated and appraised by chemistry research, industry, and environmental protection groups (Burmeister, Jokmin & Eilks, 2012). The module also includes theories of sustainability, Education for Sustainable Development (ESD), and related pedagogies to operate learning about green chemistry in secondary science education, e.g. an educational board game on green chemistry in industry (Coffey, 2014).

Although being well implemented also in many of the practical (non-educational) chemistry courses, principles related to safer and more sustainable chemistry, e.g., use of less chemicals, are not necessarily recognized – other than the student teachers – by the full chemistry students as part of green chemistry. A reason might be that there is no explicit comparison to earlier practices and thus potential for learning about sustainability is limited (Burmeister et al., 2012). Thus while the pure chemistry students are applying the principles, they often do not recognize them as any principles of sustainability or green chemistry. For instance, one of the students stated that although students are advised to use as few chemicals as possible during their laboratory activities, it was justified because chemicals are expensive and not necessarily done with the idea of reducing environmental impact by waste prevention.

This was also confirmed by one of the professors who stated that green chemistry should be presented as a philosophy to be adhered and internalized by all researchers and students who work in chemistry laboratories. So while not all students are explicitly familiar with the concept of green chemistry, he believed that the students are already doing and implementing green chemistry in the laboratory as demanded by regulations. Two of the professors also discussed the contribution of the University of Bremen in the NOP project, which aimed at altering the organic chemistry experiments for students to safer and environmentally friendlier experiments. The experiments were used by the chemistry students as part of organic chemistry modules, although due to a recent change of personnel in the organic chemistry laboratory, it was not clear whether the experiments having been designed in the project are still in use right now for chemistry students.

Interestingly, while there is no specific course in green chemistry for bachelor chemistry students, laboratories in the University of Bremen offer practical work for secondary school students to conduct experiments focusing sustainability and green chemistry (Garner, Siol & Eilks, 2015; Affeldt, Weitz, Siol, Markic & Eilks, 2015). Secondary students from many schools in Bremen and its surrounding come to the university laboratories to explicitly learn about chemistry's contribution to sustainability.

For those students pursuing to the master level studies, there is a course reflecting issues of sustainability and green chemistry as part of an excursion module towards a chemical industry plant.

Green chemistry in and as research activities

During the survey at the University of Bremen, different laboratories were visited and the research staff was interviewed. Some laboratories were part of the departments, while others were part of associated research centers. One of the research centers associated with the Department of Biology and Chemistry is the Center for Environmental Research and Sustainable Technology (UFT) with professors and researchers from different fields and departments across the different science and engineering domains. This center has more than 20 researchers with extensive range of research topics associated to sustainability.

One example of the research being done at UFT is a project related to toxicological assessments of new materials, which involves a two-step research: the first is the synthesis of the new materials and the second is its toxicological analysis. It is common for research projects to be carried out in collaboration and with funding from private companies developing new materials, including nanomaterials. The UFT assesses their materials early, even before the materials are marketed. This enables companies to have more information on whether to mass produce a certain material, or not. If the new materials are proven to be harmful to the environment, the development of the materials can be stopped or altered before companies have spent too much money for mass production, since the materials will need to be withdrawn from the market.

Interestingly, while some of the principles of green chemistry are implemented as guiding principles of research, the comprehension of the principles varied a lot among the professors and researchers. For example, while one mentioned that a simple act of switching off the light can be seen as a part of being green, another researcher did not classify his research on modern catalysts as necessarily being green. Following the ideas of green chemistry, both are actually related to it, namely the 6th principles (design for energy efficiency) and the 9th principle (the use of catalysis is preferred). This led us to believe that there is still some misunderstanding about an explicit and theory-based understanding of the terms green, environmental, or sustainable chemistry with each of them having a specific meaning and history (Centi & Perathoner, 2009; Bodner, 2014). Such confusion might also occur among Indonesian academics since this is not specific neither to the Indonesian nor German contexts (Andraos & Dicks, 2012).

The study also revealed that parts of the principles of green chemistry and sustainability became integrated thoroughly in the university central regulations. They are used as the guiding principles for every research being carried out. The main regulation regarding the use of chemicals is REACH, which is a European Union regulation concerning the Registration, Evaluation, Authorization & Restriction of Chemicals. REACH was derived into national regulations and accepted as a regulative framework to be operated as policy and guideline for practical work in research and teaching. REACH has a normative character to every work with chemicals in business, industry, research and teaching.

The principle of green chemistry which is mostly implemented in the laboratories is the 12th principle, "Inherently safer chemistry for accident prevention". This principle is clearly employed in the rules and regulations at the University of Bremen. For example, all personal and visitors have to wear safety glasses, and laboratory coats. Upon entering any laboratories one can see the name(s) of the person(s) in charge as well as risk assessment documents for the specific laboratory, which include the safety procedure and risk assessment of all chemicals in use. Every

researcher in charge of a certain research project is required to generate a written risk assessment document for their research and laboratory. The documents are displayed adjacent to the door of the laboratory so that everyone who comes to a laboratory has access to information about the chemicals and biological materials as well as safety procedures at a given laboratory. An all time up-to-date register for chemicals needs to be available for each institute and researchers and teachers are not allowed anymore to use any chemicals in procedures were a safer and more environmental friendly alternative is known.

Research on green chemistry and sustainability in terms of education is also carried out in the Institute of Science Education (IDN). The chemistry education group has done considerable activities related to green chemistry and sustainability which include empirical research, curriculum development, teacher education, and non-formal learning. The activities range from the research-based development of teaching materials to designing and implementing safer laboratory procedures. The research and innovation of teaching covers both teaching at university level and for secondary schools involving a number of chemistry and science teachers, prospective teachers, and hundreds of university and thousands of school students (Eilks, 2015).

Environmental and waste management at the University of Bremen

The reduction of waste in terms of amount and toxicity is one the main ideas of green chemistry. Thus, waste management is an important aspect that we need to consider while discussing the implementation of green chemistry. The regulations which rule the waste management in Germany, including Bremen, are very clear and strict. The University of Bremen has its own center for waste disposal which manages and collected all different types of waste produced in the university. The toxic waste is collected on a weekly basis from all laboratories at the university for temporary storage. At the waste management center, the waste is stored in different containers according to their toxicities. Some of the waste containers are placed in special storage room with controlled temperature and humidity to prevent accidents. Most of the waste is later collected by private companies for further handling, since this center only has the permit to treat a small amount of toxic waste. Interestingly, the center also has a permit to cooperate with the schools in the city of Bremen to dispose old chemicals and other toxic waste, so that schools can contact the office for waste disposal at the University of Bremen if they have toxic waste that needs to be removed.

The University of Bremen also has its own environmental management system which has been validated EMAS (Eco Management Audit Scheme) since 2004. The detailed description of environmental management includes the organization of environmental protection, which is closely interrelated to the organization of the university as a whole. The University of Bremen is one of only about 20 universities in Germany having an Environmental Management System. The system is established in the administrative division, at the scientific facilities and in specific departments. In addition, there are experts who are assigned to different administrative departments in the university. Key aspects of the environmental management system are the environmental committee with members of each department, the science council, and the staff council. The environmental committee meets regularly to discuss all aspects of environmental protection and environmental management. The comprehensive system for the environmental management also means that the University is willing to give large financial support for environmental protection, which as we will describe later in our paper, is generally lacking in higher education institutions in Indonesia.

Challenges and opportunities for Indonesia

The context with which green chemistry and ESD in general could be implemented in Indonesia clearly differs from that of Germany. The two countries are different in GDP, average level of education, culture, population size, climate, geographical conditions, and many others. However, both countries also join common visions and interests, e.g. improving in environmental protection, more efficient technologies, and improvements in education. Indonesia has also moved in the right direction in terms of ESD and environmental education. The conditions of the universities are not so different in their interests and general directions although difference in facilities, infrastructure, and the much larger number of students exist.

For Indonesia, it is suggested to start that the implementation of green chemistry from the very basic and smallest scale, i.e. classroom and laboratory activities. Today, there are many new experiments and laboratory practices created for the purpose of taking on green chemistry values and principles during laboratory work. While it seems that green organic chemistry experiments are the ones that are the most prominent to be developed (Kirchoff & Ryan, 2002; Doxcee & Hutchison, 2004), other fields such as analytical chemistry (de la Guardia & Armenta, 2010; Koel & Kaljurand, 2010; de la Guardia and Garrigues, 2011), catalytic chemistry (Anastas & Crabtree, 2009), and more recently, inorganic (Atwood, 2016) and general chemistry (Henrie, 2015) started to follow. There are several experiments being developed that are suitable for application across the curriculum, although it is also possible to use these experiments in stand-alone green chemistry course, since the two approaches offer their own pros and cons (Andraos & Dicks, 2012).

In order to successfully implement either of the two approaches, however, the professors and lecturers are of most importance. Our interviews with the Indonesian professors revealed that in general, professors and lecturers maintain their independence in terms of what to teach and how to teach in their lectures. This means that while on paper the curriculum agrees with the principles of green chemistry, there is no guarantee that it will be implemented in the classroom, although a certain level of control over what is to be included in the laboratory activities is more feasible. Resistance among lecturers to adopt new teaching methods or approaches is not uncommon, and continuous campaign and maybe guidance and professional development activities about the importance and advantages of green chemistry and sustainable education is therefore very

essential. One way to start with might be investment in chemistry teacher education. If ideas of sustainability and green processes are already implemented in school education it might be more difficult to ignore them in higher education.

Meanwhile, challenges toward greener research in chemistry are more complicated as they involve different stakeholders both in and outside universities. It seems that external funding agencies for research are not as many as in Germany, and most researchers rely on grants from either the university or the ministry of higher education or other ministries. During the initial stage of the implementation of green chemistry at the Department of Chemistry in UGM for example, there was cooperation with DAAD from Germany, and thus financial supports for both research and curricular change for laboratory activities came from both DAAD and the Ministry of Education. At present, less support is available and not all chemistry research being granted takes into account the principles of sustainability. This is a political issue of guiding the higher education system towards more sustainability.

Furthermore, financial support for conducting research also varies in different universities. Larger and more established universities under the Ministry of Education usually have more funding for research than their smaller and less established counterparts. However, not all universities are under the Ministry of Education. For example, the Ministry of Religious Affairs also administers religious based higher education institution such as State Islamic Universities (UINs) and Institute for Islamic Studies (IAINs). Since these higher education institutions are under the Ministry of Religious Affairs, the priority for research funding at these institutions are also different from that of the universities under the Ministry of Education, as they will have an emphasis on religious studies research. Thus, the campaign about green chemistry is not only important for the lecturers, but also for the university management and even at ministerial levels.

Another key aspect to the implementation of green chemistry to support ESD is waste management, and we feel that this is the area where the condition in Indonesia is particularly lacking. Regulations concerning waste management in Indonesia are already present at national, provincial and municipal levels (Indonesian Ministry of Environment and Forestry, 2016). However, the level of enactment at higher education institution still needs to be further explored. Admittedly, waste removal is expensive and not all universities pay attention to the budget needed for chemical waste removal. At present, most companies dealing with waste removal in Indonesia caters mostly to the need of industry, which produces high amount of waste. The lower amount of waste from universities means higher cost for waste transport, and it is even more expensive for institutions located outside the main islands where the chemical waste management facilities are located.

Final remarks

During this survey, the initial objective was to learn about how green chemistry and its principles are being incorporated into academic activities in higher chemistry education in Germany. However, we discovered that the discourse on green chemistry cannot really be alienated from the concern over sustainability. The 12 principles of green chemistry are in fact, "only" one of the guidelines to enable chemistry to be developed more sustainably.

The survey reveals that while not one participant was able to list the principles of green chemistry one by one, they seem to have quite a good comprehension of what the idea means, and we believe that this is the essential aim. The values of green chemistry have really been incorporated into the day-to-day laboratory activities and make learning chemistry a different way of living as e.g. described by Bodner (2014) or Dicks, Morra, Hoch and Mastronardi (2014).

A number of regulations issued to adopt the principles of sustainability clearly point out that the notion of sustainability can only be realized with strong support from all stakeholders: policy makers at the university, researchers, teaching and administrative staff as well as the students. In addition, financial support also plays vital roles to support associated research. This is a road where political action is required and a broad consensus needs to be reached, e.g. via the national chemical society in Indonesia. The direction is clear, however, the movement towards it has not yet fully started.

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