Impact of student-initiated green chemistry experiments on their knowledge, awareness and practices of environmental sustainability

Taha H1*, Suppiah V2, Khoo Y Y3, Yahaya A4, Lee T T1 and Muhamad Damanhuri M I1

1Faculty of Science and Mathematics, Sultan Idris Education University
35900 Tanjong Malim, Perak, Malaysia.
2SMK Jalan Pasir Puteh 31650 Ipoh, Perak, Malaysia
3Faculty of Management and Economics, Sultan Idris Education University
35900 Tanjong Malim, Perak, Malaysia
4E-mail: hafsah@fsmt.upsi.edu.my

Abstract. This study investigated the impact of student-initiated green chemistry experiments on their level of knowledge, awareness and practices of environmental sustainability; and on their achievement in the topic of rate of reaction. The quasi-experimental study involved 46 secondary school students with 23 students each in control and treatment groups. A set of questionnaire and a set of test were employed in the study; and data was analysed using descriptive and inferential statistical techniques. Results showed significant difference in awareness, between the groups; but a weak insignificant correlation between knowledge and awareness on green chemistry. It was also indicated awareness on green chemistry as a strong significant predictor for practice. However, results revealed no significant difference in the achievement between students undergoing traditional chemistry experiments and the green chemistry experiments. Nevertheless, students participated in designing green chemistry experiments have higher level of awareness and practice of environmental sustainability. This study recommends that teachers should empower students with suitable mechanisms to address sustainable environment issues in classroom or laboratory instruction to promote sustainable practices among them.

1. Introduction

In Malaysia, the government had first integrated environmental consideration into the sixth Malaysian plan (1991-1995) [1]. Since then, environmental education has been infused into primary and secondary schools’ curriculum. Malaysian secondary school chemistry syllabus stated, “The curriculum also aims to develop a dynamic and progressive society with a science and technology culture that values nature and works towards the preservation and conservation of the environment. Realise that scientific discoveries are the result of human endeavour to the best of his or her intellectual and mental capabilities to understand natural phenomena for the betterment of mankind. Be aware of the need to love and care for the environment and play an active role in its preservation and conservation.”) [2].

The initiation of education for sustainable development (ESD) was officially launched with a guidebook for teachers titled; Teachers’ Guide for Environmental Education developed by the
Curriculum Development Centre. Teachers are supposed to integrate the topics of sustainability in all subjects, with varying presence, depending on their relevance to the learning) [3]. However, the implementation of Environmental Education (EE) in primary and secondary schools is still unclear and seemed to have no significant impact on Malaysian green practices) [4]. It was reported Malaysia only scored 10.5% recycling rate, far too behind compared to some other countries with some almost 70% rate and we produce 0.8 kg of waste daily individually; 30000 to 33000 metric tons of waste daily. Malaysian disposed recyclable waste worth RM476 million two years ago; where primary source of waste is paper (17%) and second is plastic (9%) [5].

Recently Malaysian bauxite miners in the state of Pahang had been suspended from their mining activities for three months due to serious pollution issues. The rivers and sea water near the mines turned red, with reddish dust all over several villages and towns. Analysis carried out by the Environment Pollution Department on rivers for instance; Sungai Riau, Mabuk and Pinang found levels of aluminium, iron and mercury were at a dangerous level for mankind and will have very bad impact on aquatic organisms and water resources) [6]. If teachers could embrace ESD in the teaching and learning of chemistry, it could serve as a platform for learners in the rural areas to examine some of the environmental issues rampant in the community.

2. Literature Review
Some studies [7-8] indicated teachers’ knowledge of sustainability issues were not well-developed. Many teachers seemed knowledgeable when asked about sustainability and ESD, however, their ideas were shallow and they were unable to relate those knowledge into practises in classroom. It was also revealed that teachers lack the skills and knowledge to implement ESD [9-11]. Borg et al. [12] pointed out that by using traditional instructional methods teachers assumed learners will display appropriate sustainable actions. It seems mere campaigning or teaching sustainability in schools does not seemed to be effective in instilling sustainable practices among students.

A study [13] comparing student learning of chemistry content and experimental design skills following completion of one of the LRT (Laboratory Report Templates) experiments or a traditional experiment on identical chemistry content was conducted. Study results indicated students who completed the LRT experiment learned significantly more content and experimental skills than did students who completed the traditional experiment. This study demonstrates changing one lab from traditional to research-based has positive effects on students’ learning.

Environmental education is a way for teachers to expand science into the real world [14]. Outdoor education is place-based, involves experiential learning and fieldwork; thus could be employed to encourage learners to participate actively when learning about the environment [15]. Another study [16] showed recycling project positively affected students’ attitudes towards chemistry learning and environmental literacy. However, they also acknowledged changing their own behaviour is still difficult even when they fully understood the importance of environmental sustainable practices. Nevertheless inquiry-based teaching of life-cycle thinking could still be seen as an effective approach to nurture and enhance sustainable practices in children.

Revell [18] suggested local authority in the country should enforce harder penalties to address unsustainable practices and to meet their national emission reduction targets. This shows green practice must also be enforced rigorously by legal means and not only depends on people’s voluntary actions. If this were to be applied in Malaysia, recycling and systematic waste disposal, should be among the firsts to be enforced fiercely. This is also second by Dzulkifli [17] (ex-vice chancellor of USM, Malaysia) in his talk, posited people should be empowered with appropriate mechanisms of how they could participate to care for the environment.

Green Chemistry (GC) is rather new in Malaysia. Some chemistry teachers could not even tell what GC is exactly and how to practice it! Green chemistry is sometimes mistakenly understood as environmental chemistry. Maybe because it started as an academic research that later became noble practice championed by academia, government and NGOs. It is an approach which reduce pollution and waste from chemical reactions [19]. This approach could convey environment sustainability; as well as,
enhance students’ understanding of chemistry [20]. Karpu dewan and her team [20] tried out green chemistry experiments by downsizing the apparatus and amount of chemicals used in experiments. Their study found significant difference in students’ awareness on the environment however found no significant differences in students’ green practices. A recent study by Tuğçe, Nalan & Şenol [21] uses problem-based learning (PBL) to help students understand green chemistry better. They found students took more prominent role since the experiments were related to daily life. Hence, PBL seemed to enhance students’ level of understanding of green principles; and helped them to be more proactive in pro-environmental practices.

Mellor, Coish, Brooks, Gallagher, Mills, Kavanagh and their team [22] involved students to develop a green chemistry educational game where students need to apply green principles as they design a hypothetical, chemical product. Students’ seemed to enjoy it very much and positive impacts were observed on their awareness of sustainable practices. Another study done by Ribeiro & Machado [23] analysed the effects of reaction conditions on several green chemistry mass metrics for reactions with 1:1 and 1:3 ratios. Although there were some practical limitations to the greenness due to the complex nature of the chemistry, it was still very crucial to pay more attention to quantitative details of chemical syntheses to increase the greenness of the chemical reactions. On the other hand, Tsakeni [24] posited contemporary environmental issues offer teachers opportunities to disseminate ESD in practical work. However this could be easier said than done. For instance, Kosovo’s researchers, Spahiu, Korca & Lindemann-Matthies [15] investigated the integration of EE by 244 high school teachers. They found teachers focused on pollution and hazards of pollutants, however teachers did not seem to effectively relate them to sustainability issues. They also reported EE was also aimed at capacity-building. However, this approach was hard to implement, due to insufficient teacher resources, unsuitable class size, and very limited time. Nevertheless, interviewees insisted ideal EE should involve outdoor education, field work, and practical first-hand experiences.

3. Statement of Problem

Schools would be able to manage chemical waste more effectively if students and teachers were more knowledgeable and committed towards green chemistry practices. Solid and chemical waste from schools’ laboratory, should comply with environmental preservation principles. Therefore integrating the principles of green chemistry in a school’s chemistry laboratory plays significant role to raise awareness and understanding of all members of the school community on improving environmental sustainability practices. Hence, to play an important role as environment sustainability educationist, chemistry teachers need to equip themselves with ample knowledge and skills to disseminate the effective green practices to their students. Since the nature of chemistry lessons is very unattractive to students, teachers need to manipulate investigative and research-like approaches to trigger and enhance students’ awareness of the environment. Armed with green chemistry as the platform, chemistry teachers could involve students in designing green chemistry experiments, encouraging them to embark on their own research and seek information on green chemistry practices. This would in turn enhance students' practical knowledge and increase their pro-environment awareness and practices. Thus, based on what has been stated above, and students as the major player of the project; the objectives of this study were formulated as follows:

1. To identify differences in students’ knowledge, awareness and practices of environmental sustainability between students who did the conventional chemistry experiments from the textbook with those who developed their own green chemistry experiments.
2. To seek relationship between students’ awareness and practices of environmental sustainability.
3. To identify best predictor that contribute to students’ practices of environmental sustainability.
4. To identify differences in students’ performance in the topic of rate of reaction between students who did the conventional chemistry experiments from the textbook with those who developed their own green chemistry experiments.

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4. Method

4.1. Sample
A total of 46 secondary school students were involved in the study. 23 students were undergoing traditional chemistry experiment (control group) and 23 students developed and carried out green chemistry experiments (experimental group).

4.2. Instruments
A set of questionnaires of 48 items was used to elicit students’ knowledge, awareness and practices of environmental sustainability, while a paper and pencil test in the topic of rate of reaction was employed to gauge students’ grasp of the topic. The questionnaire was constructed by the research team based on extensive literature analysis and some items were adapted from Tee [25], Mohd Zubair [26], Nurbaiy [27] customized to Malaysian secondary school students. The test on rate of reaction (ROR) was constructed based on Malaysian secondary school chemistry syllabus. A pilot study conducted on 30 respondents found the validity and reliability of the instruments were high (Cohen’s kappa = 0.94 and Cronbach’s alpha = 0.91 for the questionnaires; and content validity agreement from another three experts for the ROR’s test was 0.99 and inter-rater reliability $r = 0.98$).

4.3. Research Procedures
Pre-test on the ROR’s topic were first given to both groups. The control and experimental groups were formed from intact classes which were equivalent in terms of performance and background. The control group then proceeded with direct teaching by a teacher (selected from the research team) using the conventional chemistry experiments from the text book provided by the Malaysian Ministry of Education. This group managed to finish off the topic in six school periods. At the same time, the treatment group started to design green chemistry experiments of the topic under the supervision of another member of the research team. Development of these experiments was based on students’ research on the 12 principles of green chemistry; such as using benign materials used in daily life and by downsizing the amount of chemicals used; to study factors affecting the ROR. A series of brainstorming and debate sessions took part throughout the project. Students first tried out their ideas during the chemistry lab periods before finalizing the green experiments. The treatment group finished 4 teaching periods later than the control group. Both groups were guided to carry out research, to manage information, develop critical and creative thinking and build their coherent analysis of the experiments. Table 1 shows brief descriptions of some of the green chemistry experiments developed by the treatment group.

| Factor affecting ROR | Conventional experiment | Green chemistry experiment |
|----------------------|-------------------------|----------------------------|
| Total surface area   | Zinc metal and hydrochloric acid | Vinegar and eggshells |
| Concentration        | Sodium thiosulphate, sulphuric acid | Lemon juice, Alka Seltzer pills |
| Temperature          | Sodium thiosulphate, sulphuric acid | Vinegar, eggshells |

Once treatments were completed, a post-test on ROR was conducted to both groups intended to determine the effectiveness of green chemistry experiments on student achievement in the topic and after that the post-treatment questionnaires was administered to study the impact of the GC experiments on students’ knowledge, awareness and practices of environmental sustainability.

5. Results and Discussion
First, differences in students’ compatibility was examined by comparing the pre-test scores of both groups on the topic of ROR.
Table 2. Independent t-test of the pre-test on the topic.

| Group    | Mean  | Mean diff. | Sd. diff. | t     | df | Sig. (2-tailed) |
|----------|-------|------------|-----------|-------|----|-----------------|
| Experiment | 15.00 | 14.56      | 0.44      | 2.534 | 44 | 0.394            |

*Significance level 0.05

Table 2 shows the mean of the experimental group was 15.00, while the control group was 14.56 (t = 0.868 and p > 0.05). This shows there was no significant difference of both groups’ performance in the pre-test. Thus the two groups were equivalent in terms of prior knowledge. Next, table 3 shows there was no significant difference in the achievement between students undergoing traditional chemistry experiments and the green chemistry (GC) experiments.

Table 3. Independent t-test of the post-test on the topic.

| Group    | Mean  | Mean diff. | Sd. diff. | t     | df | Sig. (2-tailed) |
|----------|-------|------------|-----------|-------|----|-----------------|
| Experiment | 18.88 | 18.36      | 0.52      | 2.12  | 41 | 0.289            |

*Significance level 0.05, N = 43

The post-test results demonstrates there was no significant difference in the post-test mean scores between the experimental and control groups, (t = 5.933, and p > 0.05). The results indicates the achievement of the experimental and control groups were not significantly different, although the mean scores for the experimental group (mean = 18.88) was slightly higher than the control (mean = 18.36).

Below, table 4 shows the comparison of the post-questionnaire results for both groups on the knowledge of green chemistry (GC). The mean value shows a significant difference between the groups. The treatment group shows a much higher mean score, indicating a significant increase of their knowledge of GC after completing the green chemistry experiments project. Students seemed to gain more knowledge when the topic was taught using green chemistry experiments. They were compelled to look for more information on green experiments, had many brain-storming sessions and heated discussions on how to ensure the experiments could really be done realistically. They even tried out the experiments several times before finalizing their report. These exercises of active learning might be the contributing factors of the present results of this study.

Table 4. Mean score of post-test for knowledge GC.

| Group    | N   | Mean  | SD   | t     | df | Sig |
|----------|-----|-------|------|-------|----|-----|
| Experiment | 23  | 15.13 | 1.46 | 10.62 | 41 | .000 |
| Control   | 20  | 10.30 | 1.52 |       |    |     |

*Significance level 0.05, N = 43

Table 5 shows the pre and post-test comparison for awareness of GC for students who were involved in the green chemistry experiments. Result shows there was significant difference in awareness, with the mean value showed substantial increase after the exposure towards green chemistry experiments. These seemed to support research done by Cullifer [28] that reported students’ understanding of green chemistry was significantly enhanced when presented with two real-world scenarios and applied benefits-costs-risks analysis that emphasizes a decreasing dependence on limited non-renewable resources and an increasing focus on preventing pollution by-products of the chemical industry.

Table 5. Mean scores for experimental group on awareness on GC.

| Group    | N   | Mean  | SD   | t     | df | Sig |
|----------|-----|-------|------|-------|----|-----|
| Pre-test | 23  | 61.56 | 5.84 | 1.58  | 44 | .021|
| Post-test| 23  | 84.34 | 5.92 |       |    |     |

*Significance level 0.05, N = 46
Next, correlation between students’ knowledge and awareness on green chemistry was also examined. Table 6 shows the correlation between knowledge and awareness on green chemistry among the participants. The results show a weak insignificant correlation ($r = 0.08$ and $p > 0.05$) between students’ knowledge and their awareness of green chemistry. This result seems to support findings of a research done by Aminrad, Syed Zakaria, Hadi & Sakari [29] and Ahmad, Md Noor & Ismail [30] that also revealed weak relationship between knowledge and awareness of environmental issues.

Table 6. Correlation between students’ knowledge and awareness on GC.

| Variables         | 1      | 2      | Sig   |
|-------------------|--------|--------|-------|
| Attitude          |        | 0.080  | 0.462 |
| Knowledge         |        |        |       |

*Significance level 0.05, N = 46

Although the literature suggests knowledge could be a viable predictor for environmental attitude of GC [31], this study does not seem to yield similar results. Next, Table 7 seems to indicate awareness on green chemistry as a strong significant predictor for practice. The percentage of the predictor is 60.5 percent towards the criterion variable and however, as expected, knowledge does not significantly predict practice of GC ($p > .05$).

Table 7. Multiple regression analysis for the predictor for practice of GC.

| Model             | B    | Standard error | t     | Sig   |
|-------------------|------|----------------|-------|-------|
| Constant          | 27.894 | 4.802          | 5.83  | .000  |
| Knowledge GC      | .149 | .151           | .984  | .450  |
| Awareness GC      | 1.78 | .156           | 11.44 | .000  |

$R^2 = .614$, $AR^2 = .605$

Though we might logically think and believe that when one is more knowledgeable about the environment, they will, in turn, be more inclined to be more ‘green’ or act toward the environment more responsibly, this is not apparent in this study. The pro-environmental behaviors have to come from people’s true understanding and commitment. The global change in the 21st. century changes with fast-paced technological advance, plus emerging life styles and values, are now exposing nature with serious environmental damage. Pollution from industrial emissions, waste management, and sustainability of water supply, and energy efficiency; need to be addressed now, in order for younger generation to be able to inherit a clean and beautiful Malaysia. Prevention is always better than cure. Thus, preventing the environmental catastrophe in the future is a better option before it is too late to regret.

6. Conclusion
This study revealed student-initiated green chemistry experiments have positive impact on students’ knowledge, awareness and practice of green chemistry. It is evident from the study that encouraging students’ participation in designing green experiments enhances their sustainable practice. Integrating green chemistry in school chemistry experiments triggers students’ sense of responsibility towards the environment. It would be excellent if every school subjects called for students’ involvement in such a way that they would feel responsible for environment in whatever they do. Integrating sustainable practices in lessons actively would be an integral parts to cultivate the awareness among students. Furthermore, it is also recommended proper training for teachers so that they will be able to teach their students effectively. Teachers need to be equipped with more ‘hands on’ skills rather than mere theories and facts to deliver effective green chemistry lessons. If teachers were not environmentally literate, it will be almost impossible for them to produce environmentally literate students. ESD in schools should call for more collaborative participation and engagement from all school staff, parents and local community to instill pro-environmental practice into children and community at large.
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