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# The Effects of "Green Chemistry" on Secondary School Students' Understanding and Motivation

**Abstract** As an initial effort to reorient the current Malaysian chemistry curriculum, *green chemistry* was developed. In this study for the purpose of investigating the effectiveness of the green chemistry curriculum on secondary school students' understanding of chemistry concepts a quasi-experimental design was used. One group pre test post test design was used to measure the changes in the motivation before and after the treatment. Two classes were randomly assigned to experimental ($N$ = 35) and control group ($N$ = 32). Following the intervention, an ANCOVA with pre-test as the covariate showed the experimental group achieved significantly higher ($M_E$ = 23.40, $SD_E$ = 1.39) than the control group ($M_C$ = 12.78, $SD_C$ = 1.71), $F$ = 1018.26, $p <$ .0001. The effect size was very large, $d$ = 18.7. The unbiased JCS Bayes factor (JCS << 1/100) suggests that the evidence is substantial in favor of the alternative hypothesis of group differences. The analysis of the pre-post semi-structured interviews, concerning motivation found that a significant number of students changed from low to high self-efficacy belief, high task value belief, transformed their goals of learning towards mastery orientation, and were more interested towards learning chemistry after the intervention.

**Keywords** Green chemistry, chemistry achievement, motivation to learn, secondary school

## Introduction

In an increasingly populated, globalized, and complex world, environmental issues have come to the forefront of the problems of, and dangers for, human existence. These problems are such that a single scientific field or even science alone can no longer cope with the ensemble of ramifications that come with each problem. Interdisciplinarity therefore becomes *de rigueur* even when the ecological issues pertain to a local concern such as access to biologically and chemically uncontaminated water (Roth et al. 2004). Educating the public on the importance of conserving the environment, especially the public of developing nations such as Malaysia in this study, should be expected to contribute to save the environment from further destruction. Green chemistry – an interdisciplinary approach to chemistry with a focusing on the local environment – has shown great promise for raising knowledge, attitudes, and motivation among pre-service science teachers (Karpudewan, Zurida and Roth 2012b, c). This study was designed to investigate the effects of a green chemistry curriculum on students' acquisition of chemistry concepts and their motivation to study chemistry.

## Background

Green chemistry, also known as sustainable chemistry, refers to the design of chemical products and processes that reduce or eliminate the use and generation of hazardous substances. Twelve principles have been identified as constituting the core of a green chemistry (Anastas and Warner 1998). The "greening" of chemistry means that this science is conducted in a more responsible manner because work processes are designed to minimize their impact on the environment. Green chemistry also has become a new orientation in the teaching of the subject (Wardencki, Curylo and Namiesnik 2005) and has been integrated into secondary and higher education curricula (Karpudewan et al. 2012b, c). Studies show that courses in green chemistry can enhance students' critical thinking, problem solving, and communicative skills required for understanding sustainable development both locally and globally (Parrish 2007). With green chemistry, students learn to address environmental problems, because they feel empowered towards solving concrete problems in familiar settings (Haack et al. 2005). This, in turn, can be considered to be part of an agenda to educate students for engaged, democratic citizenship, where students use science to improve environmental and personal health, which gives meaning and satisfaction to their learning activities (Roth and Désautels 2004).

The implementation of green chemistry experiments and activities is consistent with other context-based chemistry courses that lead to enhanced conceptual understandings in relation to chemical thermodynamics and chemical bonds (Barker and Millar 2000). However, context-based approaches tend to result in positive affective development only, with little effect on cognitive development (e.g. Jong 2006). Various possible reasons are cited for the failure of the context-based approach. For example, from the students' perspective the contexts may not be really relevant; and this discourages them to study the chemistry content. Additionally, the contexts can be confusing for students, because mundane meanings of concepts often do not match science meanings. From the curricular perspective, little understanding of concepts occurs when the context is used after introduction of the theory, as illustration thereof, and when the context is not incorporated in testing and evaluation. Moreover, teachers often consider the contexts in textbooks as useful for learning but they see the teaching thereof as too time-consuming and therefore tend to skip these. When the green chemistry curriculum provided a context that was experienced as relevant by the students, there was little or no confusion about how everyday life meanings related to science meanings, especially when curriculum was integrated into the curriculum in such a way that the implementation did not add to the already existing overwhelming amount of curricular content (Karpudewan et al. 2012a; 2012b; 2012c).

The construct of motivation has different dimensions. In this study, self-efficacy belief, task value belief, goal orientation, and affect orientation will be investigated due to existence of  evidence in science education of their strong association of these dimensions with (conceptual change) learning (Tseng, Tuan and Chin 2010; Yen, Tuan and Liao 2011). *Self-efficacy belief* refers to individuals' perception of their ability in particular situations or accomplishing learning tasks (Printrich and Schunk 1996). *Task value belief* refers to students' beliefs about interest, utility, and importance of a course (Wigfield and Eccles 2000). *Goal orientations* are defined as individuals' underlying purposes when approaching, engaging in, and responding to achievement situations (e.g., Kaplan and Maehr 2007). The most commonly used contrasting goal orientations are *mastery* and *performance* goals. Mastery goals refer to the intention of mastering the task to improve competence (e.g., Ames 1992); and performance goals refer to the concern of performing better than others (e.g., Dweck 1986). *Affect orientations* refer to *interest* and *anxiety* in performing the task (e.g., Schunk et al. 2008).

Green chemistry experiments, as students in this study completed them, have shown to contribute to creating learning environments that reflect on self-efficacy belief. For instances, role play strategy used in the post-lab section, provided a platform for the students to presume a model and tend to performance as well as the role assigned to them and thereby experiences higher self-efficacy (Bandura 1982). Green chemistry, as implemented here, embeds task value belief as the content emphasizes on the personal importance in thinking about solutions for current and future real world issues; students enjoy learning chemistry concepts when it allows them to focus on real world issues. Simultaneously, caring for real world issues reflects an intrinsic value as well. Further reasons for our hypothesis that green chemistry simultaneously enhances learning and motivation derives from the fact that a study with pre-service teachers' demonstrated decisive evidence for the hypothesis that green chemistry caused changes in motivation toward the environment (Karpudewan, Ismail and Roth 2012c).

## Methods

### *Study Design*

A quasi-experimental design (Shadish, Cook and Campbell 2002) was used to test the null hypothesis of no difference between achievement levels in a regularly taught chemistry curriculum and a curriculum following the principles of green chemistry; and a one-group pretest-posttest design involving an experimental group only (Shadish et al. 2002) was used to evaluate the changes in motivation. We conducted an (a) experimental test of the null hypothesis $H_0$ that there will be no difference between a green chemistry and a regular chemistry curriculum on achievement; and (b) exploratory study concerning the null hypotheses $H_0^i$ (i = 1 . . 4) of no change in four motivation-associated aspects and the associated changes in student discourses. These two designs are appropriate and acceptable for this kind study because they are commonly used to identify empirical evidence related to the effectiveness of suggested approaches; and the one-group pre-post test design focuses more on indentifying the changes occurred after going through the intervention (Shadish et al. 2002).

### *Research Participants and Context*

Two classes of Malaysian Form 5 students (average age 17) participated in this study and were randomly assigned to experimental ($N = 35$; 19 male, 16 female) and control groups ($N = 32$; 18 male, 14 female). The research took place in two suburban, fully governmentally funded co-educational schools from the same district. Both schools have basic amenities such as computer labs and science. We also matched the two participating teachers on as many factors as possible: the Ministry of Education identified both as “Excellent Teachers” in terms of subject matter (content knowledge) and pedagogical knowledge; both were female teachers with 12 and 13 years of service, respectively; both teachers had the same training in the same institution and subject matter focus; and they were the students’ regular instructors and had taught them chemistry since Form 4 (i.e., for more than a year). Both teachers had written clearly stated lesson objectives made available to the students so that these would know the learning outcomes, nature of the assignments, and grading policies. Both teachers tended to ask “why” and “how” questions and encouraged students to predict what would happen next. Both appeared to be warm, accessible, enthusiastic, and caring and fostered strong relationships with their students.

### *Interventions in the Experimental and Control Groups*

Chemistry was taught as a laboratory-based course where each experiment would take an entire week. . Both groups conducted the same six experiments covering reaction rate and the chemistry of carbon compounds found in the national curriculum of Malaysia (CDC 2006). The experimental group conducted a "greener version" of the experiments and the comparison group conducted traditional experiments that are currently found in the national curriculum. Five 40-minute periods (two double and one single) per week were allocated to the chemistry lessons. Laboratory practical work normally took place during the two double periods. In this study, each of the six experiments was conducted during a double period; discussion of the experiments took place during the subsequent double period. The single period was used for completing exercises and laboratory reports. In this manner, a total of 200 minutes weekly were allocated to each experiment. The total intervention therefore amounted to 1,200 minutes or 20 hours of instructional time.

For the purpose of this study, six green chemistry experiments were obtained from various sources (Cann and Connelly 2000; Doxsee and Hutchison 2004) and tailored to the mandatory Malaysian curriculum. The "greening" is achieved in terms of the chemicals used. For example, in the experiments on the topic of carbon chemistry, environmentally benign materials were used. Thus, whereas glucose is commonly used to produce ethanol in the traditional laboratory, the same chemical is produced from molasses in the green version of the course. Molasses is a by-product of sugar production from sugar cane, one of the main agricultural products of the country. As another example, the bromination of alkenes is typically taught using elemental $Br_2$ in a solvent, such as carbon tetrachloride or methylene chloride. Whereas this is a useful way to teach the reaction in a lecture setting, its high toxicity makes it inappropriate for use in a student laboratory. In the green chemistry course, the bromination of alkenes is accomplished by generating $Br_2$ *in situ* using HBr and $H_2O_2$ according to the reaction $2\ HBr + H_2O_2 \rightarrow Br_2 + 2\ H_2O$. The handling of $Br_2$ can thus be avoided. Once $Br_2$ is formed, an alkene is added to the flask to be brominated .

In our study, the green chemistry curriculum also involved a change of the learning environment. For example apart from producing biodiesel from palm oil, the students were asked to discuss and justify whether the production of biodiesel from palm oil is really green. In this context, students are required to relate what they know to the real-world scenario and have to think freely and explore the given context. Independent thinking as observed in green chemistry classroom has been related to the desire for deep understanding of science concepts that ultimately enhances students' motivation in science learning and lead to greater achievement (Nolen and Haladyna 1990). The green chemistry curriculum also values active participation and collaboration, which have been shown to lead to higher levels of interest and intrinsic motivation in science (Bell, Urhahne, Schanze and Ploetzner 2010; Stavrova and Urhahne 2010).

On the other hand, the traditional curriculum used in the control group encourages rote memorization of the concepts without making learning relevant; and it discourages participatory types of learning. The same six experiments were taught in this more conventional approach using toxic and harmful chemicals. Similar to the experimental group, the six experiments in the control group were conducted over the course of six weeks with one experiment per week. During each week, the first double period was used to perform the experiments, the subsequent double period for dissuasions, and the following single period was devoted to doing exercises and the laboratory report. (Further details on the similarities and differences between the experimental and control curriculum are found in the *supplementary materials*.)

*Interviews*

The purpose of the interviews was to assess the degree to which students' motivation changed within the experimental group in the course of experiencing green chemistry. Approximately sixty-minute interviews were conducted with 20 randomly selected students from the experimental group before and after participating in the experimental curriculum. Since, these students were from the same group with similar characteristics the interview participants were randomly selected. The interview questions were intended to solicit students' motivation towards learning chemistry. The questions asked included "What is your view on the importance of chemistry task given by the teacher? Do you belief the task is important?" and "What is your view on the importance of chemistry task given by the teacher? Do you belief the task is important?" Following the experimental curriculum, students were asked to reflect on questions such as "After going through a series of green chemistry experiments, how would you describe your capability in completing the chemistry tasks?" "How did the experiences obtained from the chemistry experiments affect your beliefs on the importance of the chemistry tasks?" "How were your intentions to solve chemistry tasks affected?" All interviews were conducted in English by the lead author.

The interviews were audiotaped, transcribed, and then analyzed in a qualitative manner of data inspection and coding, constant comparison, analytic induction, and description (Goetz and LeCompte 1984). Data were coded according to self-efficacy belief (low, high), task value belief (low, high), goal orientation (mastery vs. performance), and affect orientation (anxiety, interest). Reliability of the analysis unit with the themes was determined through Cohen's kappa, which refers to the "degree, significance, and sampling stability of [two or more raters'] agreement" (Cohen 1960, p. 38). The interview transcripts were given to experts involved in qualitative research and chemistry teaching and learning. The inter-rater reliability between the raters was $\kappa >$ 0.75, which indicates a good degree of agreement (Landis and Koch 1977).

### *Chemistry Achievement Test (CAT)*

A 25-item test for concepts covered on the topics rate of reaction and chemistry of carbon compounds was constructed for the purpose of identifying students' understanding of 10 chemistry concepts associated with the state curriculum. The content and face validity of CAT was determined by a group of experts in chemistry education and secondary school chemistry teachers with 5 to 10 years of experience in teaching chemistry. The 45-minute CAT had been piloted with 52 Form 5 students not included in the main study. As the multiple-choice sections of the items in the CAT were dichotomously scored (0 for incorrect and 1 for correct), a Kuder-Richardson 20 (*Kr-20*) was used resulting in a value of 0.72. This was considered to be acceptable for an instrument of this type.

The questions in CAT were designed based on Bloom's Taxonomy of the cognitive learning domain (Bloom 1956). Accordingly, the questions were classified into six categories. Out of the 25 items, 10 questions focus on the knowledge category, 7 questions fall into the comprehension category, 2 questions measure if students can apply a concept, 3 analysis questions require students to distinguish between facts and inferences, 2 synthesis question ask students to build a structure or pattern from diverse elements, and 1 evaluative question requires making judgments about the value of ideas or materials. These categories, in the order listed, reflect an increasing degree of difficulty. The CAT, therefore, includes a mix of questions along the continuum from rote to conceptual learning. For both groups, CAT was administered twice: as pretest and, during the week following the completion of the treatment, as post-test.

## Findings

### *Achievement in Chemistry*

To evaluate students' understanding of chemistry, the pre-test was used as a covariate in an ANCOVA design to control for variance deriving from correlations between achievement and prior knowledge. The test for homogeneity of regression in experimental and control group showed no difference ($F(1,63) = 3.16$, $p > .05$).

The subsequent test of group differences was calculated for adjusted means. The ANCOVA revealed statistically detectable differences between the adjusted means of the experimental ($M_E$ = 23.40, $SD_E$ = 1.39) and control groups ($M_C$ = 12.78, $SD_C$ = 1.71) in favor of the former ($F$ = 1018.26, $p < .0001$) (Table 1). This corresponds to decisive evidence against the null hypothesis of no difference (Wetzels et al. 2011). Using the larger standard deviation of the control group as reference, the effect size $d$ = 18.7 turns out to be "very large." An unbiased two-sample Bayes test yields JZS = $1.49 \cdot 10^{-38}$, which, being smaller than 1/100, is interpreted as constituting *very strong evidence* in favor of the alternative hypothesis (Wetzels et al. 2011).[1]

**««««« Insert Table 1 about here »»»»»**

*Changes in Motivation*

In this study, changes in motivation were investigated using a one-group pretest-posttest design, which can indeed lead to strong evidence for causation if "the plausibility of alternative explanations for the treatment effect" is reduced (Shadish et al. 2002, p. 106).

*Quantitative Results* The pre-intervention and post-intervention interviews – coded along the four dimensions of self-efficacy belief, task value belief, goal orientation, and affect orientation – showed that there were indeed substantial changes. As Table 2 shows, there are significantly larger numbers of participants reflecting higher levels of motivation than before the intervention. There are a considerable number of students who have changed self-efficacy ($N$ = 11), task value belief ($N$ = 13), goal orientation ($N$ = 7), and affect orientation ($N$ = 12). All of these changes were from low to high levels; no student with high levels changed to low levels. In other words, those students who started with low self-efficacy, task value belief, goal orientation, and affect orientation (65%, 81%, 50%, and 75%, respectively) experienced change to high values on these parameters. All of these numbers indicate a tremendous impact on students with the greatest need for improving motivation levels.

The null hypothesis would state in each case that the expected number of students in each category (high, low) would be the same after the green chemistry unit as before, which is equivalent to saying that all counts would appear in the main diagonal of the four matrices in Table 1. Three of four $\chi^2$ tests – conducted at

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[1] The calculator available at http://pcl.missouri.edu/bf-two-sample and the scores used to describe interpretive values given by Wetzels et al. (2011) are inversely related.

Bonferroni-adjusted α values $\alpha_{adj} = \alpha/4$ to keep the experiment-wise at $\alpha = .05$ – comparing the actually observed distributions to those expected under the null hypothesis provide *substantial* evidence – i.e., $p < .001$ (Wetzels et al. 2011) – against the null hypotheses of no change in self-efficacy belief ($\chi^2(1) = 47.45$, $p < .000025$), task value belief ($\chi^2(1) = 52.81$, $p < .000025$), and affect orientation ($\chi^2(1) = 45.00$, $p < .000025$). For goal orientation the evidence is very good against the null hypothesis ($\chi^2(1) = 11.67$, $p < .0025$). That is, the substantial learning differences in the experimental group – when compared to the standard curriculum approach – were associated with substantial changes in the motivation orientations.

**«««««« Insert Table 2 about here »»»»»»**

*Qualitative Results* A significant number of individuals changed from a low level to a high level on each of the four dimensions. The following interview excerpts exhibit the changes that were observed.

*Self-efficacy belief* denotes the judgment of speakers concerning their capability in accomplishing a given task. When students have high self-efficacy beliefs, they consider themselves capable of accomplishing the given learning tasks, which positively affects their problem-solving success generally and in chemistry particularly (Taasoobshirazi and Glynn 2009). Individuals with low self-efficacy may believe – as expressed in statements such as "failed to solve the problems" and "cannot do it" – that things are tougher than these really are and students possess narrower visions of how best to solve a problem (Pajares 1996). Consider the following interview excerpts with Ahmad that taken together exemplify a change from low self-efficacy belief prior to instruction towards high self-efficacy belief following instruction.

> Pre-intervention: Whenever I am given a task in chemistry lessons, I will have this weird feeling something like my thinking is blocked. I just cannot think further. Most of the time I failed to complete the task.
>
> Post-intervention: After the experience with green chemistry, I can feel a change. I tend to enjoy the lesson and the task as well. Initial attempts will be difficult, but somehow I will manage to solve them. My performance improved and I think I am more capable now. [For example], we learned about biodiesel . . . that was interesting. I actually had a chance to look at and touch the biodiesel. It is lighter, less viscous [than regular diesel], and the color is also lighter. In this experiment, I understood what the transesterification process is all about. I can write the chemical equation for this process as well.

Initially, Ahmad described his experience with respect to chemistry in terms of a weird feeling associated with a sense that his thinking is blocked. He experienced failure to complete the assigned tasks, which he attributed to the blocked thinking that did not allow him to reflect further. During the second interview, Ahmad displayed a decided optimism with respect to chemistry learning. He articulated having experienced a change and then elaborated by saying that he now enjoyed the lessons. Although he might still experience difficulties, which previously caused his thinking to be blocked, he now feels able to manage them. He suggested that not only did his performance improve but so did his capabilities. Ahmad also said that the enjoyment of the lesson resulted from the experience with green chemistry lab, where he had opportunities to get his hands on biodiesel.

*Task value belief* is a student's individual belief concerning the importance of the task and the value of the task to him/her. Consider the following interview with Jeevan. Prior to the green chemistry curriculum, he exhibited low task value belief as denoted by the expression "chemistry got no value" and "[chemistry] is little useful."

> Pre-intervention: I think that the tasks I always involved in relation to chemistry got no value. The knowledge is less important. I think it is little useful as well.
>
> Post-intervention: I think the task is important. The information obtained from completing the tasks is valuable. At times I apply this information when I am doing household chores.

Following the curriculum unit, Jeevan expressed high task value beliefs, which he considers important and valuable, because he can relate what he had learned to his household chores. Asked about a specific thing that he has learned that made tasks valuable, Jeevan answered:

> Post-intervention: We learned many new and current things in the biodiesel experiment. The issue on whether biodiesel is really green means that we should not only talk about using biodiesel for the environment, but that there are other things that we need to consider. Biodiesel takes food plants, but people cannot go without food. Other aspects of peoples' lives, too, are affected.

The answer shows that Jeevan understood the complex problematic that comes with the production of biodiesel: It affects food production, perhaps even taking away plants from the food chain to the transportation sector.

*Goal orientation* is the term that denotes the purposes underlying students' participation in the given tasks (Nicholls 1992). Goals may orient the individual toward performance or mastery. A change from the former to the latter orientation is exemplified in the following excerpts from the interviews with Gaaya.

> Pre-intervention: Chemistry is a very difficult subject for me. But I still participate in the learning task, because I need to perform in the examination. I need to get all A's. So, even though I hate the subject I got no choice. I need to be on a par with, or better than, my friends.
>
> Post-intervention: Last week my chemistry teacher talked about global warming and greenhouse gases while we were involved in green chemistry lab. I think we should learn this aspect, because the weather now is extremely hot. I feel like I wanted to learn more. I can actually apply what the teacher said in class that day. I believe this type of task will make us aware of what is happening. We analyzed the life cycle of petroleum diesel and biodiesel; this part was very interesting and opened my mind to local and global scenarios. I think everyone needs to have this knowledge.

Gaaya initially used a discourse typical of a performance orientation when she spoke about performing (well) on examinations, a point that he elaborated by saying that she "*needs to be* on par with or better than his friends." Here, knowing chemistry is not valued for itself. What matters is performance, or rather, to be at least as good as others. After the experience of the green chemistry curriculum, Gaaya drew on a discourse of mastery goal orientation. She began the excerpt by recalling the lesson when the teacher talked about global warming and greenhouse gases and how these aspects have invoked her *wanting* to know more and her assertion that everyone must have this knowledge.

*Affect orientation* denotes students' emotional reactions to the task (Mousoulides and Philippou 2005). The excerpts from the interview with Chin Chin before and after intervention exemplify the discursive changes form anxiety orientation to interest orientation.

> Pre-intervention: My heart feels very heavy on the days I have chemistry lesson. I will start to worry about the lesson one day earlier. The heavy feeling will be in me until the chemistry lesson finishes. The moment the chemistry lesson is over, I will feel a big relief. I presume this because I lose out to my friends in the exam. I will get lower grades for chemistry.
>
> Post-intervention: Green chemistry activities are interesting. The worries that I usually carry to the chemistry lesson are no more. I enjoyed the lessons and participated in the activities. Even my friends and teacher noticed the difference in me. They encouraged me to keep it up. The interest provoked me to think and talk about chemistry lessons with my friend even after the class. That rarely happened previously.

Chin Chin initially talked about her anxieties associated with chemistry not only while she was in the lesson but also beginning on the preceding day. She described experiencing a relief when the lesson was over. In this excerpt, the anxiety discourse is related to the one previously identified as performance orientation when she expressed worries about “los[ing] out to [her] friends” and about “get[ting] lower grades for chemistry.” Following the intervention, Chin Chin talked about finding green chemistry interesting. She directly related it to the decrease in her worries about the subject matter. She articulated enjoyment that she also described to have been visible to her teachers and peers.

**Discussion and Conclusion**

This study was designed to investigate the effect a green chemistry curriculum has on (a) achievement (as compared to the regular curriculum) and (b) motivational factors of the experimental students. The underlying assumption was that there indeed is no better place to teach children how to lead a sustainable lifestyle than at school, where they spend so much of their everyday lives. As response to this call of school as the best place to learn, Kong et al. (2013) proposed including 3D-Textbook into teaching and learning of environmental education. Green chemistry, as suggested here, is another alternative to integrate sustainability in teaching and learning chemistry. The integration of green chemistry is consistent with the calls for the circular contextualization, which seeks the integration of school and everyday knowledge (Fernandes et al. 2012).

*Substantial* evidence is provided in support of the hypothesis that the green chemistry curriculum brought about the achievement differences between experimental and control groups. Our analyses of the interviews also show that a statistically significant number of students had changed their orientations on the four motivational dimensions of self-efficacy belief, task value belief, goal orientation, and affect orientation. Our qualitative interpretive analyses exemplify the changes in discourse exhibited in experimental students’ talk about their experiences and the effects of the curriculum on their knowledge, attitudes, and values. The discourse change is a good reflection of the results that we obtained by quantitative means. Because of existing empirical associations between science learning (achievement, conceptual change) and motivation for which there are good theoretical models (Krapp and Prenzel 2011), there is likely to be a mutual determination between incrementing levels of positive motivation and incrementing levels of understanding. Future ethnographic studies that use observation of student engagement, concurrent interviews, and evaluations of student understanding should be able to document how these two aspects affect one another over the course of a green chemistry curriculum such as the one used here.

The improved conceptual understanding identified among experimental group students is likely due to the nature of the green chemistry, consistent with the claims that meaningful learning results when students are enabled to connect canonical science concepts with a real-world context (Gilbert 2006). The students' confidence in the chemistry concepts increased as they used ideas from situations familiar to them, which allowed them to consolidate with science concepts. The real world examples generated in the lesson created opportunities for applying the knowledge to practical contexts, consistent with previous studies in which instructional strategies focusing on application of the knowledge resulted in improved conceptual understandings (e.g. King 2012).

The four motivational belief constructs that we investigated in this study are important antecedents for overcoming the current crisis of low student achievement and enrollment of students in science courses (Sjoberg and Schreiner 2010). Research shows that self-efficacy belief, task value belief, goal orientation and interest are consistently associated with conceptual change process (e.g., Velayutham, Aldridge and Fraser (2011). One study investigated the effect of motivational factors on conceptual learning process in a digital learning context and reported that improved achievement of the students correlate with these motivational constructs (Chung-Hsein, Hsiao-Lin and Chi-Chin 2010). Hence, improved motivation and achievement in the context of green chemistry as reported in this study is consistent with other studies.

Science practical work frequently is linked to increased motivation and interest in learning science. However, practical work tends to emphasize short-term engagement to particular lesson rather than motivation in learning science in general (Abrahams 2009); and this confusion of short- and long-term effects on interest drives the ways in which science is taught in school (Vedder-Weiss and Fortus 2011). Green chemistry experiments, as used in this study, might indeed constitute a solution to this insufficiency because of the interdisciplinary and transformative nature of green chemistry. In transformative experiences, students use science concepts to see and experience their everyday world in new, meaningful ways. These experiences tend to be linked with conceptual understandings and motivations (Pugh et al. 2010).

The indicators provided are very strong in favor of the treatment. Yet there are limitations to our study. This investigation was designed as a quasi-experimental study involving two classes taught by different teachers in different schools to measure the effectiveness of green chemistry. Although the schools lie in the same district serving the same population, and although the two teachers have similar subject-matter backgrounds (same concentration), educational experiences (studied at same university, obtaining the same degree), and teaching experiences (same length, in same context) – effects that fall into the category of *local history* (Shadish et al. 2002) – there are threats to the internal validity that cannot be excluded by our design. One threat is *selection-maturation*, whereby the participants in one group develop on a dimension that the other does not. A one-group pretest-posttest design was used in the exploratory part of the study that focuses on measuring changes in motivation. This design threatens its internal validity about the intervention as the cause of motivational change.

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