JPII 11(4) (2022) 600-610

Jurnal Pendidikan IPA Indonesia

http://journal.unnes.ac.id/index.php/jpii

GREEN CHEMISTRY EDUCATION IN THE EMERGING ECONOMIES IN ASIA

M. B. Jovero*[1] and J. P. Picardal[2]

[1]Surigao del Norte State University, Surigao City Philippines
[2]Cebu Normal University, Cebu City, Philippines

DOI: 10.15294/jpii.v11i4.39112

Accepted: September 20th 2022. Approved: December 29th 2022. Published: December 30th 2022

ABSTRACT

This paper aims to investigate and synthesize literature exploring the current state of Green Chemistry Education (GCE) in the emerging economies in Asia to determine what has been done and the continuing projects for the promotion of Green Chemistry (GC). The researchers used the integrative literature review approach to examine qualitative, quantitative, and mixed methods and empirical and theoretical literature related to GCE. This approach includes (a) problem identification, (b) search for structured literature, (c) data evaluation, (d) data analysis, and (e) presentation of findings. Published studies revealed that most initiatives in integrating GC principles in emerging economies in Asia focused on the secondary and tertiary levels but not graduate studies and non-chemistry-related courses. Most of its progress has been observed in Organic Chemistry and General Chemistry. Results also revealed that the barriers that hampered integrating GCE are pedagogical resources (insufficient or unavailability of time, financial and technological resources) and pedagogical content knowledge (misconceptions about GC, lack of expertise, and the need to update technical knowledge). It can be concluded that even in the initial stage of implementation of green chemistry education in the emerging economies in Asia, and despite numerous documented barriers, proactive efforts are being made by numerous institutions and even individuals who are tenaciously advocating green chemistry. These efforts are enriched through various educational programs, learner-centered pedagogical practices, and strategies that enhance teachers' and students' content knowledge and skills. Finally, economics is a major factor in determining a country's state of Green Chemistry as the economic condition can be credited to outstanding or dismal achievements.

Keywords: green chemistry education; emerging economies in Asia; integrative literature review

INTRODUCTION

Green Chemistry (GC) is recognized as a powerful approach for preventing pollution and sustaining the earth; it employs scientific techniques to address pressing environmental issues. (Karpudewan et al., 2012; U.S. EPA, 2021). The concept of GC was initially developed in response to the US Pollution Prevention Act of 1990 and a need to discover a solution to environmental issues. This act aims to minimize raw materials extraction, develop cost-effective products and processes, and eliminate hazardous chemicals and waste while preserving and enhancing the performance required to meet critical and growing societal demands (Haack & Hutchison, 2016). Just as GC and the application of its principles received a great deal of interest from the industrial and scientific fields in essentially the most economically developed nations, it is also becoming mainstream in educational sectors, particularly in practices and research. This is known as Green Chemistry Education (GCE) (Haack & Hutchison, 2016; Płotka-Wasylka et al., 2018; and Li & Eilks, 2021).

Green Chemistry Education (GCE) incorporates green chemistry principles, new concepts, contents, and pedagogical approaches across

*Correspondence Address
E-mail: mjovero@ssct.edu.ph

chemistry education, including curriculum development, teaching, learning, and outreach (Wang et al., 2018; Płotka-Wasylka et al., 2018). The GCE's primary goal is to advance scientific understanding regarding sustainable development and help current, and future generations acquire the necessary skills. Educating future chemists, policymakers, teachers, and society on the essential concepts and practices of GC is the ultimate way to impact and provide a practical solution to current environmental problems. Additionally, it will enable chemists to lead in creating a healthier, safer, and more environmentally friendly world.

GCE has gained considerable attention and is now being implemented worldwide (Płotka-Wasylka et al., 2018). Several studies in Western developed and industrialized countries introduced GC principles in the curriculum (Burmeister et al., 2012; Bodlalo et al., 2013; Marteel-Parrish, & Newcity, 2017). Studies proved that educating citizens by introducing GC programs seems to be a workable strategy for fostering an environmental orientation across an entire country (Karpudewan et al., 2015). However, even though GCE is the norm in the majority of advanced economies, such initiatives have a long way to go in most emerging countries, especially in those countries where green chemistry education is not yet prevalent and environmental consciousness means little or nothing to the citizenry (Barra & González, 2018).

Asia Pacific countries with emerging economies such as China, Malaysia, Indonesia, India, Korea, Philippines, Taiwan, and Thailand (Miziołek & Feder-Sempach, 2019; OECD, 2021) have experienced an industrial revolution that paved the way for rapid technological development and plays a significant part in today's economy and modern society (Chen, & Reniers, 2020; Yun and KPMG Global Energy Institute, 2014). However, the industry's rapid expansion has resulted in many negative issues, such as rising pollution problems, a growing population, and high energy and water consumption, which caused irreversible environmental damage and threatened future generations' well-being (OECD, 2021). On top of these environmental and health issues are the industrial chemical disasters resulting in thousands of deaths (Reniers & Cozzani, 2013; Chen, & Reniers, 2020). These environmental and health issues and catastrophes are considered a global concern that demands a unified effort from all nations. The necessity for the emerging economies in Asia to learn from the previous experiences of advanced nations, especially lessons on development and environmental management, is more emphasized today. As the demand for industrial products increases, so does the need for a populace knowledgeable about addressing environmental issues. Undoubtedly, the introduction and application of GC in Asia's emerging economies have become a top priority. There are many studies conducted in emerging economies in Asia on GC principles application in industrial sectors, particularly in improving its "tarnished" industrial image and repositioning itself as the advocate and driver of Green Chemistry in the twenty-first century (Matus et al., 2012; Płotka-Wasylka et al., 2018). There is also a dearth of research that documents the current status and investigates the efforts of emerging Asian countries to implement GC principles in the academe.

Thus, this study aims to shed light on the research gaps mentioned and intends to investigate and synthesize literature exploring the current state and the efforts made to introduce Green Chemistry in education, particularly in Asian countries with emerging economies. This paper is instrumental in assisting and providing educators and future researchers with a practical and feasible path to improve green chemistry education, particularly in designing pedagogical materials and developing approaches. This way, the fast-evolving industry trends in emerging economies in Asia will adopt and promote cost-effective, less hazardous, and environment-friendly products.

METHODS

An integrative literature review technique by Toronto & Remington (2020) was undertaken to investigate research related to green chemistry education in emerging Asian countries. This approach is appropriate for this study as it analyzes qualitative, quantitative, and mixed methods and empirical and theoretical literature related to GCE to provide a holistic understanding of a phenomenon or topic. This approach includes (a) problem identification, (b) search for structured literature, (c) data evaluation, (d) data analysis, and (e) presentation of findings. First, Problem Identification. The following questions served as a guide for this integrative literature review:

1. What is the current state of Green Chemistry Education in emerging Asian countries?
2. What are the barriers that hampered the success of integrating and putting green chemistry education into practice?

Second, Search for Structured Literature. A three-phase search method was used in this study: (i) database search; (ii) screening for duplicates; and (iii) applying inclusion and exclusion criteria to make sure rigor of the literature review (Figure 1).

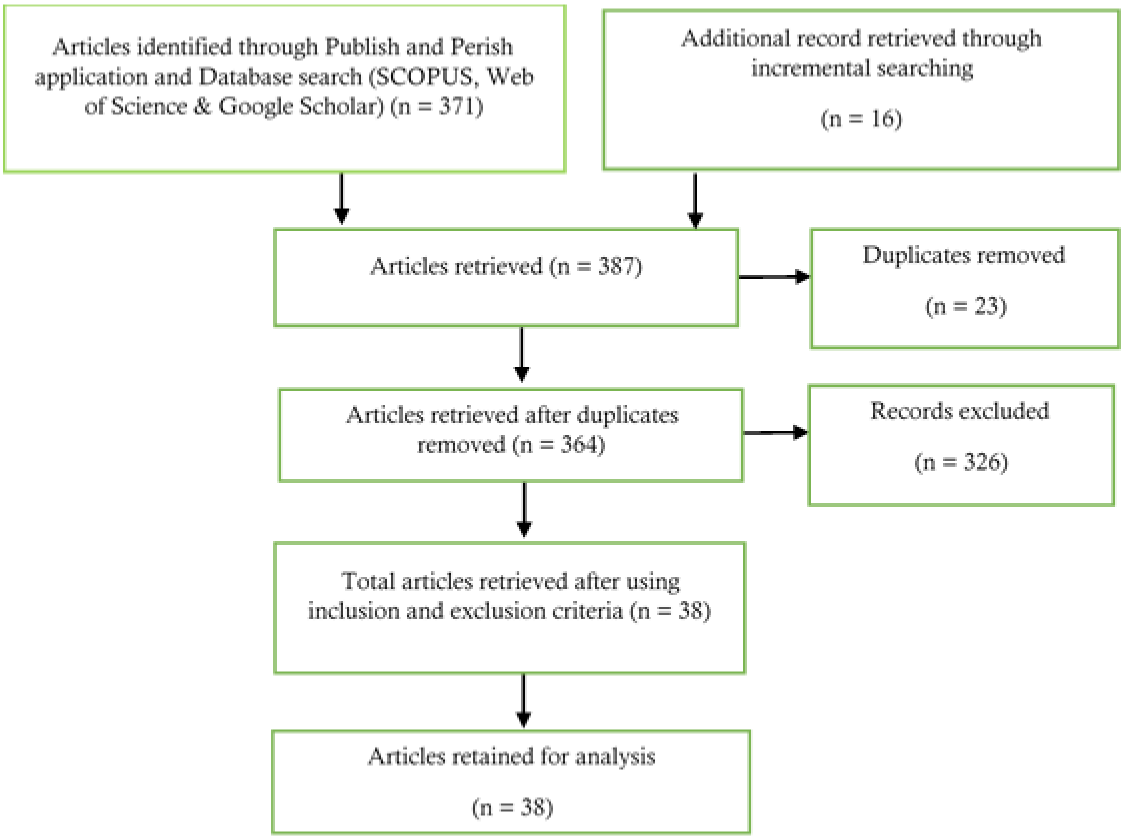

Figure 1. Flow Diagram of Integrative Review

i. Database search: Electronic databases such as SCOPUS, Web of Science, and Google Scholar were searched to access previous studies on green chemistry education (GCE) in emerging Asian countries.

ii. Search terms: In searching for information in each database, the following terms were used: green chemistry education, green chemistry integration, approaches/ strategies/ laboratory activities related to GC, teachers' perception, awareness, knowledge about GC, and barriers and challenges in the implementation of GC principles. Search terms were also combined through Boolean operators like AND/OR. The researchers entered each of the key terms individually in the English language. However, not all papers identified by this search and labeled by corresponding terms were entirely in line with contemporary understandings of "green chemistry education" from a theoretical point of view. All relevant papers were read to avoid bias. Some papers were excluded due to apparent mismatches with the search term intentions.

iii. Screening for duplicates. The articles were screened manually to remove duplicate articles by reading the abstract of each article. Twenty-three (23) duplicates were detected and removed from the list. Thus, the remaining 364 were then carried to the next level of analysis.

iv. Inclusion and exclusion criteria. Specific inclusion criteria were defined to select and include only relevant studies for the research topic identified from the databases: the study is published in journals; written in English; peer-reviewed; conducted in emerging Asian countries; the complete/ full text is accessible; includes empirical, reviews, case studies, or descriptions of green chemistry practices and published in the period 2011 to 2021. This review paper did not include the proceeding of congresses, conference papers, books, book chapters, editorials, and unpublished manuscripts and was not conducted in an educational environment (primary, secondary, tertiary education, or graduate studies).

Third, Data Evaluation: Quality Appraisal. Since there was a broad representation of relevant research, the data quality was evaluated and structured on two criteria: (i) relevance of the data and (ii) rigor of the methodology (Toronto & Remington, 2020). The degree to which the study was relevant to the research questions serves as the criterion for determining the relevance of the data. In addition, the methodological review takes into account the research design, sample selection, ethical integrity, reliability, and validity. A review of possible research ensures that they all meet the inclusion and exclusion criteria being set.

Fourth, Data Analysis. The current integrative review adopted the five steps in analyzing the potential studies (Toronto & Remington, 2020). These include data reduction, data display, data comparison, drawing of conclusions, and verification.

RESULTS AND DISCUSSION

The results of this integrative review are organized by the two research questions that served as the study's guiding principles, such as: what is the current state of Green Chemistry Education in emerging Asian countries, and what are the barriers that hampered the success of integrating and putting green chemistry education into practice.

Implementing and promoting green chemistry education across all levels, starting in basic education, proceeding through a tertiary level, and continuing throughout the graduate studies curriculum, is the easiest and most practical way to guarantee that these initiatives will focus on sustainability. In this regard, the subsequent paragraphs discussed the updates on scholarly endeavors regarding the current state of GCE in emerging economies in Asia regarding integrating GC concepts and principles into the chemistry curriculum at all levels of education. This also considered several pedagogical approaches, laboratory activities, and resources used to promote GCE. Teachers' and students' perceptions, awareness, and understanding of GC concepts and principles were also included.

Published studies revealed that most of the initiatives in the integration of GC concepts and principles in emerging economies in Asia have focused on the secondary level (Kanapathy et al., 2017; Li & Eilks, 2021) and tertiary level, particularly at the pre-service science teacher curriculum (Karpudewan et al., 2012; Karpudewan, 2020). Most of its progress has been observed in the teaching strategies and GC laboratory experiments and explicitly taught in Organic Chemistry and General Chemistry (Wang et al., 2018; Ma & Shengli, 2020). However, the infusion of GCE into the curriculum not related to chemistry and graduate studies has received surprisingly little attention.

Incorporating green chemistry concepts into the pre-service teaching curriculum is undeniably important. Pre-service teachers can educate future chemists and other future professionals from a broad range of interdisciplinary fields about sustaining the environment through the principles of GC (Aubrecht et al., 2019). Exposing the pre-service teachers to the importance, practices, and principles of green chemistry early in their career can help them build a concrete foundation for GCE (Karpudewan et al., 2012). Karpudewan et al. (2020) pointed out that exposing students to the numerous teaching tools and laboratory exercises used to teach green chemistry effectively will allow them to use these instructional techniques shortly after being hired as chemistry instructors.

On the other hand, similar to the western countries' initiative – the Presidential Green Chemistry Award (Collins, 2015; Haack & Hutchison, 2016), the Taiwan education and environmental protection agencies have hosted the Green Chemistry creativity Biannual Competition (Li & Eilks, 2021) for senior secondary students which inspire many students and teachers to innovate green chemistry experiments. In addition, the 2017 revision of the General Senior Secondary School Chemistry Curriculum Standard has also emphasized teaching students about the ideas and principles of green chemistry in the secondary chemistry curriculum. (Ma & Shengli, 2020). This most recent edition invites students to embrace responsibility and actively engage in social issues related to chemistry while assisting students in developing an understanding and sense of sustainable development (Kanapathy et al., 2017).

In addition to the initiative conducted by several institutions and universities in terms of implementing GC is the establishment of the Center for Green Chemistry (Cui et al., 2011; Wang et al., 2018) to research biomass conversion. Another is the deployment of the Distance Education Program, which delivers teaching resources for green chemistry using live internet and satellite-based video conferencing technology in addition to online resources (Tantayanon et al., 2011). Moreover, many institutions offered an open course on Green Chemistry and Sustainable Development and a public course on Green Chemical Technology, which focused on environmental-friendly substances and green hydrocarbon oxidation processes (Wang et al., 2018). Meanwhile, little has been published regarding implementing GC in the graduate studies curriculum. Although Wang et al. (2018) acknowledged the development of a Doctoral program in Green Chemistry in China, they did not discuss how this program was implemented. Thus, there is a need for novel empirical research, particularly in pedagogical approaches, experiments, and case studies on graduate studies. One way to publicize green chemistry education in graduate studies is through research engagement and outreach.

Furthermore, the transition to a more sustainable world necessitates highly trained chemists and specialists from various interdisciplinary domains. Students enrolled in business, ethics, law, and nontechnical courses related to industries who may never set foot in a chemistry laboratory nevertheless have a stake in the future of green chemistry. They must be informed of the potential unintended consequences of dangerous chemicals because addressing environmental issues calls for appropriate information and efficient educational techniques (Chen et al., 2020). Thus, integrating GC into non-chemistry-related courses is crucial to preparing the next generation of students for a sustainable future. However, the analysis reveals that the infusion of GCE into the curriculum not related to chemistry has received surprisingly little attention. Hence, innovative empirical research is required, notably in educational approaches and experiments in non-chemistry-related fields.

Generally, the incorporation and use of green chemistry ideas in Chemistry curricula in Asian countries with emerging economies appear to be at the preliminary stage. Even though some studies have claimed that the GCE was initially discussed in graduate studies, comprehensive implementation is still lacking. In addition, there appears to be only a weak link between chemistry education and chemistry research. At the moment, this resource is not maximized. Thus, there is a lot of research potential that needs to be considered.

The evaluated articles revealed various student-centered instructional approaches designed and developed to enhance pedagogical conceptual understanding and motivate students at all levels to learn and appreciate the value of green chemistry. The approach includes: (i) Presenting green chemistry through debate and making arguments (Karpudewan et al., 2016) improves students' argumentative skills and conceptual knowledge of green chemistry (Walker & Sampson, 2013). Argumentation instruction greatly aids students in explaining phenomena in a clear and comprehensible manner, as well as constructing, justifying, validating explanations, and assessing the acceptability of arguments (Chin et al, 2014; Chen et al., 2020); (ii) Developing a dynamic problem-based pedagogy utilized real-world contexts to teach undergraduates the relevance and importance of the roles of chemistry in sustainable development. Through this activity, they experienced and successfully engaged in an environmental sustainability project to address environmental issues, such as designing a learning experience while developing a practical technique utilizing the Green Chemistry approach (Nurbaity & Ridwan, 2016); (iii) Using a contextualized inquiry-based chemistry training and outreach activity by taking advantage of local resources or contexts about GCE resulted in positive opinions on all attributes, including curiosity, perceived ability, value, and commitment (Li & Eilks, 2021); (iv) Constructing an inquiry learning model for a green chemistry course for student teachers. This is based on writing and presenting research papers on green chemistry topics in groups (Li & Eilks, 2021); (v) Introducing the "asking-thinking-doing" model for GC practical work to enhance students' innovative thinking (Wang et al., 2010). Carrying out specific events and outreach activities based on GC, such as poster exhibitions, green chemistry competitions, and on-site visiting related industries or plant activities (Li & Eilks, 2021); (vi) Students' internships in industry and participation in research work about green chemistry were also verified as effective methods for GCE teaching (Chen et al., 2020); (vii) Implementing socio-scientific issues (SSI) in GCE is also a new concern. Cha et al. (2021) designed a strategy that allows the students to create comic drawings on the organic chemical-based SSI that are relevant to their daily lives. Aside from this applied technique, Cha et al (2020) suggested a strategy in which students are expected to compose a reflective essay incorporating the element of SSI to boost creative and critical thinking skills and increase students' interest in the basics. SSIs are real-world issues that are socially significant, rooted in science, and generally connected to approaches of systems thinking, which is holistic thinking highlighting the interdependence and interactions of the components of the chemical system with others (Mahaffy et al., 2018).

The results show that the increasing acceptance and implementation of green chemistry worldwide necessitates a paradigm shift in educational strategies and approaches. This entails shifting from teacher-centered to student-centered approaches, transmissive learning to discovery, theoretical learning to experiential learning, and linking theories to practices. This new paradigm could potentially be a way to address the issue in the cookbooks in which students follow the procedures in the cookbook robotically and without thinking about what they are doing. Involving students in challenging worldviews through student-centered pedagogical approaches will increase students' real-world learning opportunities. Moreover, most pedagogical techniques or approaches across all levels favor group or collaborative learning. Finally, implementing GCE across all levels remains mainly at the classroom teaching level. Thus, public or private institutions should also consider collaborating with other non-government agencies to provide opportunities for students to learn outside the four walls of the classroom.

Green chemistry education requires a student-centered learning approach linked to practical experiences or laboratory work (Burmeister et al., 2012; Karpudewan et al., 2015). Chemistry laboratory and practical work motivate students' learning, assist students in understanding theories, and allow learners to attain practical ability with the scientific method (Listyarini et al., 2019). There have been some modifications implemented to meet the green experiment's standards. Different tailor-made experiments integrating principles of green chemistry have been developed in emerging Asian countries, including (i) replacing the current non-beneficial and harmful experiments and utilizing environmentally benign raw materials (Santos & Guidote, 2015; Wang et al., 2020; Kiwfo et al., 2021); (ii) designing Context-Based Green Chemistry Experiments (CBGCEs (Karpudewan & Mathanasegaran, 2018; Karpudewan et al., 2015; Bodner, 2015); (iii) popularizing microscale chemistry experiments or known as Small Scale Chemistry (SSC) (Tantayun, 2015; Wang et al., 2018; Listyarini et al., 2019; Zhou, 2019); (iv) developing of laboratory manual (Karpudewan et al., 2012); (v) emphasizing accreditation of policies, rules, and regulations regarding chemical safety in every green chemistry research laboratory (Tantayanon, 2015).

The application of environmentally benign raw materials and replacement of the non-beneficial and harmful chemistry experiments was demonstrated in most chemistry education in emerging Asian countries. For instance, the guava leaf extracts were transformed into a ready-to-use green reagent powder. They were utilized as a natural-reagent assay kit for determining iron (Santos & Guidote, 2015; Kiwfo et al., 2021), molasses as glucose to produce ethanol, producing Br2 in situ while brominating alkenes with HBr and H_2O_2 (Karpudewan, 2020). They also utilized lauric acid and Vitamin C instead of hazardous substances such as naphthalene, sodium thiosulphate, and corncobs as raw materials to synthesize biodiesel, ethanol, and sunscreen (Zhou et al., 2019).

On the other hand, microscale chemistry experiments or known as Small Scale Chemistry (SSC), have been popularized and implemented in countries like Thailand (Tantayanon, 2015) and China (Zhou, 2019) as a solution to tackle the shortage and high cost of laboratory facilities problems (Wang et al., 2018; Listyarini, 2019; Listyarini et al., 2019). SSC is an approach to conducting chemistry experiments using a reduced amount of chemicals, simple equipment, and smaller glassware or a change of the glassware materials to plastic materials which is gaining attention not only in secondary education but also in higher education (Mafumiko et al., 2013; Wang et al., 2018; Listyarini, 2019;). While the SSC approach has become widely used in advanced economies like the US, Switzerland, and Germany, this is only now becoming popular in emerging economies in Asia.

Meanwhile, designing Context-Based Green Chemistry Experiments (CBGCEs) (Karpudewan et al., 2015; Karpudewan & Mathanasegaran, 2018) is another initiative in which the learning is contextualized based on real-life examples to allow the students to learn through actual, practical experience with a subject rather than just the theoretical components. For instance, the rise of bread or cakes when yeast is used as a catalyst was utilized to contextualize learning about catalysts in a reaction (Karpudewan & Mathanasegaran, 2018).

Another effort conducted in emerging Asian countries to implement green chemistry is the production of a laboratory manual intended for secondary students and pre-service teachers (Karpudewan et al., 2012). The majority of the experiments were obtained from various sources and presented in a manner where environmental issues were addressed and tailored to suit the local context. Besides, accreditation of policies, rules, and regulations regarding chemical safety in every green chemistry research laboratory has been emphasized, and the students passed safety training and a chemical safety test before gaining permission to conduct research was guaranteed (Tantayanon, 2015).

All in all, the GC, as mentioned above, laboratory experiments and their improved methods for practical work are very diverse. Laboratory experiments were carried out safely and effectively outside the standard laboratory setting, even in the lack of expensive laboratory hardware. Most green chemistry experiments are feasible because they were only integrated into the existing curriculum. In other words, the curriculum has not been changed, but the existing chemistry experiments have been integrated with the principles of GC and presented in a more environmentally friendly manner. In addition, the experiments employed are often concerned with fostering students' abilities beyond average practical skills. Green chemistry's transdisciplinary and transformative orientation enables students to apply scientific ideas to their everyday lives in novel, relevant ways.

Teachers play a crucial role in influencing each student's perspective of the world, the potential for economic success, engagement in decision-making, community involvement, and interactions with the surrounding environments. Future professionals, workers, leaders, parents, and global citizens are all educated by teachers. Hence, finding ways to integrate GC into teaching is primarily driven by teacher initiatives. However, if a teacher does not have firsthand experience in the subject, it would be difficult to anticipate learners to understand GC. As a result, before such GC principles can be taught to the next generation of workers, teachers must first be equipped with sufficient knowledge of GC principles.

Although the existing GCE investigations into secondary and tertiary teachers are limited, the following finding of this integrative review is unambiguous. Results show that many teachers, even with a background in chemistry or related subjects, possess only basic knowledge of green chemistry (Carangue et al., 2021). This is similar to the results found for pre-service teachers (Nurbaity et al., 2016). This finding is in contrast to a study conducted by Auliah et al. (2018) which found that almost all vocational school teachers are familiar with GC. However, it was also revealed that teachers' attitudes toward implementing GC into the chemistry learning process were unfavorable. This is since misconceptions about GC still exist among teachers handling chemistry subjects and many more in unrelated sciences courses (Ma & Hu, 2020). Studies also revealed that teachers' understanding of the GC concepts had not been sufficiently elaborated by schooling, and they just had heard it from public media and environmental conferences (Chen et al., 2020). This is because, in the current education system in most countries with emerging economies, GC is not offered as a core subject. Instead, it is typically offered as an elective course. Since GCE is not mandatory, most pre-service teachers choose not to enroll in GC. Goldman et al. (2006) emphasized that the lack of exposure to GC principles and insufficient preparation of teachers led to the unwelcoming behavior and attitude towards GC and other related issues associated with the introduction of environmental education into the classroom. UNESCO also added that the major factor in curricular failure and one of the most significant problems with GCE is inadequate training and preparation of most teachers.

The results imply that the effort of Asian countries with emerging economies to integrate GC has not yet been fully implemented. Even though some studies have claimed that the GCE was initially discussed, wide implementation is still lacking. Thus, the universities and other teacher-education institutions should be prepared and engaged in greening the existing curriculum for chemistry teaching methods courses to address the ultimate goal of GCE.

Within the context of the emerging economy, experiencing significant change may result in several types of barriers that hamper the success of the integration and implementation of GCE. In this integrative review, the identified barriers were generalized into two (2) major categories: (i) pedagogical resources (insufficient or unavailability of educational materials; (ii) pedagogical content knowledge (misconceptions about green chemistry and lack of expertise and the need to update technical knowledge) (Matus et al., 2012; Wang et al., 2018; Kanapathy et al., 2019; Carangue et al., 2021). Similarly, most of these challenges also exist among industrialized and developed countries during their attempt to incorporate green chemistry into the curriculum (Haack & Hutchison, 2016)

First, (i) Pedagogical resources. Several studies have considered pedagogical resources as time, financial, and technological resources (Kanapathy et al., 2019). Time was seen as a scarce resource in enhancing preferred educational changes and affects the character and orientation of teachers' work. Since teachers are mandated to keep up with the curricula, they believe that they do not have the time to enhance their teaching and engage in interdisciplinary work (Borg et al., 2012). This is in line with previous findings stating that an overcrowded curriculum impacts time for innovation, research, or even discussion with colleagues (Burmeister et al., 2012).

Moreover, financial resource is another major concern since it increases the risk of achieving all the intended goals and future initiatives related to sustainability. Besides that, in most academic institutions, sustainability may not be a priority, and funding has been reallocated to other institutional concerns. It was recommended that the creation of specific funding schemes be able to facilitate the implementation of GC concepts in the curriculum among teachers.

On the other hand, even though it was mentioned in the literature that the majority of green chemistry pedagogical resources that have been developed are in the field of organic chemistry (Andraos & Dicks 2012), however, several studies have claimed that GC resources and education materials are insufficient (Carangue et al., 2021). Most organic undergraduate textbooks offer GC principles and examples as "optional material," typically as sidebars and vignettes (Płotka-Wasylka et al., 2018). As a result, there is an increasing need to broaden the selection of teaching resources from chemical subdisciplines, particularly from analytical and physical chemistry, as well as from domains unrelated to chemistry (Andraos & Dicks, 2012).

Second, (ii) Pedagogical content knowledge. Educators face challenges in infusing green chemistry concepts and principles in teaching chemistry and other non-related disciplines even though it was mentioned that integrating and implementing GC into all levels of education, from primary to graduate courses, would greatly help education as a whole (Karpudewan & Kulandaisamy, 2018; Płotka-Wasylka et al., 2018). Unfortunately, not many professionals are experts in this field, which frequently hinders initiatives. Probably the main reason for this is that GC courses are considered electives and are not mandatory to complete the requirements of an undergraduate chemistry program. It is described as a "soft" subject and skills learned are not necessary for any organic chemistry courses and at any undergraduate level (Andraos & Dicks 2012; Ma and Hu, 2020). Thus, there is a growing need for expanding pedagogical content knowledge from various fields, particularly chemistry. Recommendations from previous studies stated that the terminology of GC would be standardized to avoid misconceptions and to enable the direct and effective application of the Twelve Principles. In addition, academicians need professional development and training programs in GC to give them ample opportunity to obtain a better awareness and conceptual understanding of sustainability, reconsider current teaching techniques, and obtain the necessary skills to teach sustainable development (Cebrián et al., 2015).

CONCLUSION

GCE is gaining much attention as a significant catalyst for change in chemistry education in developed western countries and in emerging economies in Asia. Literature shows proactive efforts are being made by numerous institutions and even individuals who are tenaciously advocating GC and sustainable development to advance GCE. However, numerous documented barriers – including insufficient or unavailability of educational resources such as time, financial and technological resources as well as lack of pedagogical content knowledge about GC – a variety of effective student-centered pedagogical practices and approaches such as classroom teaching strategies and laboratory experiments have been developed and implemented to incorporate green chemistry principles into education. These approaches are modified to meet the green chemistry standards and are designed not just to enhance pedagogical conceptual understanding but to motivate students across all levels to learn and appreciate the value of green chemistry. Moreover, economics is a major factor in determining a country's state of Green Chemistry, as the economic condition can be credited to outstanding or dismal achievements. Although much progress has been achieved in incorporating green chemistry concepts, approaches, and technologies into modern chemistry curricula in Asian countries with emerging economies, it appears to be at the preliminary stage, and there is still much work to be done: (1) The universities and other teacher-education institutions should be prepared and engaged in greening the existing curriculum for chemistry teaching methods courses to address the ultimate goal of GCE; (2) Collaboration between education institutions and non-government agencies to provide opportunities for students to learn green chemistry outside the four walls of the classroom; (3) Pre-service and in-service chemistry instructors should receive specialized training in the relevant green chemistry pedagogical content knowledge and skills; (4) Finally, novel empirical research, particularly in pedagogical approaches, experiments, and case studies on graduate studies and non-chemistry-related courses, is required

REFERENCES

Andraos, J., & Dicks, A. P. (2012). Green chemistry teaching in higher education: a review of effective practices. *Chemistry Education Research and Practice, 13*(2).

Aubrecht, K. B., Bourgeois, M., Brush, E. J., MacKellar, J., & Wissinger, J. E. (2019). Integrating green chemistry in the curriculum: Building student skills in systems thinking, safety, and sustainability. *Journal of Chemical Education, 96*(12)

Auliah, A. Muharram, & Mulyadi, (2018). Indonesian teachers' perceptions on green chemistry principles: a case study of a chemical analyst vocational school. In *Journal of Physics: Conference Series* (Vol. 1028, No. 1, p. 012042).

Barra, R., & González, P. (2018). Sustainable chemistry challenges from a developing country perspective: Education, plastic pollution, and beyond. *Current Opinion in Green and Sustainable Chemistry, 9*, 40-44.

Bodlalo, L. H., Sabbaghan, M., & Jome, S. M. R. E. (2013). A comparative study in green chemistry education curriculum in America and China. *Procedia-Social and Behavioral Sciences, 90*, 288-292.

Bodner, G. M. (2015). Understanding the change toward greener chemistry by those who do the chemistry and those who teach chemistry. In *Relevant Chemistry Education* (pp. 263-284).

Borg, C., Gericke, N., Höglund, H. O., & Bergman, E. (2012). The barriers encountered by teachers implementing education for sustainable development: Discipline bound differences and teaching traditions. *Research in Science & Technological Education, 30*(2), 185-207.

Burmeister, M., Rauch, F., & Eilks, I. (2012). Education for Sustainable Development (ESD) and chemistry education. *Chemistry Education Research and Practice, 13*(2)

Carangue, D. G., Geverola, I. J. R., Jovero, M. B., Lopez, E. N. B., Pizaña, A. D., Salmo, J. M., ... & Picardal, J. P. (2021). Green Chemistry Education among Senior High School Chemistry Teachers: Knowledge, Perceptions, and Level of Integration. *Recoletos Multidisciplinary Research Journal, 9*(2).

Cebrián, G., Grace, M., & Humphris, D. (2015). An action research project for embedding education for sustainable development in a university curriculum: Processes and prospects. In Integrative Approaches to Sustainable Development at University Level (pp. 707-720). Springer, Cham.

Cha, J., Kim, H. B., Kan, S. Y., Foo, W. Y., Low, X. Y., Ow, J. Y., ... & Chia, P. W. (2021). Integrating organic chemical-based socio-scientific issues comics into chemistry classroom: expanding chemists' toolbox. *Green Chemistry Letters and Reviews, 14*(4), 699-709.

Cha, J., Kan, S. Y., & Chia, P. W. (2020). Inclusion of Organic Chemical Based Socio-Scientific Issues and Action-Based Activity to Promote sustainability in the Basic Organic Chemistry Course. *J. Sustain. Sci. Manag, 15*, 30-39.

Chen, C., & Reniers, G. (2020). Chemical industry in China: The current status, safety problems, and pathways for future sustainable development. *Safety science, 128*, 104741.

Chen, T. L., Kim, H., Pan, S. Y., Tseng, P. C., Lin, Y. P., & Chiang, P. C. (2020). Implementation of green chemistry principles in circular economy system towards sustainable development goals: Challenges and perspectives. *Science of the Total Environment*, 716, 136998.

Chinn, C. A., Rinehart, R. W., & Buckland, L. A. (2014). Epistemic cognition and evaluating information: Applying the AIR model of epistemic cognition. *Processing inaccurate information: Theoretical and applied perspectives from cognitive science and the educational sciences*, 425-453.

Collins, T. J. (2015). Review of the twenty-three-year evolution of the first university course in green chemistry: teaching future leaders how to create sustainable societies. *Journal of Cleaner Production, 140*, 93-110.

Cui, L., Li, L., Zhang, A., Pan, G., Bao, D., & Chang, A. (2011). Biochar amendment greatly reduces rice Cd uptake in a contaminated paddy soil: a two-year field experiment. *BioResources*, *6*(3), 2605-2618.

Eilks, I., & Rauch, F. (2012). Sustainable development and green chemistry in chemistry education. Chemistry *Education Research and Practice, 13*(2), 57-58.

Goldman, D., Yavetz, B., & Pe'er, S. (2006). Environmental literacy in teacher training in Israel: Environmental behavior of new students. *The Journal of Environmental Education, 38*(1), 3-22.

Haack, J. A., & Hutchison, J. E. (2016). Green chemistry education: 25 years of progress and 25 years ahead.

Kanapathy, S., Lee, K. E., Sivapalan, S., Mokhtar, M., Zakaria, S. Z. S., & Zahidi, A. M. (2019). Sustainable development concept in the chemistry curriculum: An exploration of foundation students' perspective. *International Journal of Sustainability in Higher Education*.

Karpudewan, M. (2020). Malaysian Experiences of Incorporating Green Chemistry into Teaching and Learning of Chemistry across Secondary and Tertiary Education. In *Chemistry Education for a Sustainable Society* Volume 1: High School, Outreach, & Global Perspectives (pp. 161-174). American Chemical Society.

Karpudewan, M., & Kulandaisamy, Y. (2018). Malaysian teachers' insights into implementing green chemistry experiments in secondary schools. *Current Opinion in Green and Sustainable Chemistry, 13*, 113-117.

Karpudewan, M., Roth, W. M., & Ismail, Z. (2015). Education in Green Chemistry: Incorporating Green Chemistry into Chemistry Teaching Methods Courses at the Universiti Sains Malaysia. In *Worldwide Trends in Green Chemistry Education*.

Karpudewan, M., & Mathanasegaran, K. (2018). Exploring the use of context-based green chemistry experiments in understanding the effects of concentration and catalyst on the rate of reaction. In *Asia-Pacific Forum on Science Learning & Teaching* (Vol. 19, No. 2).

Karpudewan, M., Roth, W. M., & Sinniah, D. (2016). The role of green chemistry activities in fostering secondary school students' understanding of acid-base concepts and argumentation skills. *Chemistry Education Research and Practice, 17*(4), 893-901.

Karpudewan, M., Roth, W. M., & Ismail, Z. (2015). The effects of "Green Chemistry" on secondary school students' understanding and motivation. *The Asia-Pacific Education Researcher, 24*(1), 35-43.

Karpudewan, M., Roth, W. M., & Abdullah, M. N. S. B. (2015). Enhancing primary school students' knowledge about global warming and environmental attitude using climate change activities. *International Journal of Science Education, 37*(1), 31-54.

Karpudewan, M., Ismail, Z., & Roth, W. M. (2012). Promoting pro-environmental attitudes and reported behaviors of Malaysian pre-service teachers using green chemistry experiments. *Environmental Education Research, 18*(3), 375-389.

Karpudewan, M., Ismail, Z., & Roth, W. M. (2012). Ensuring sustainability of tomorrow through green chemistry integrated with sustainable development concepts (SDCs). *Chemistry Education Research and Practice, 13*(2), 120-127.

Karpudewan, M., Ismail, Z., & Roth, W. M. (2012). Fostering pre-service teachers' self-determined environmental motivation through green chemistry experiments. *Journal of Science Teacher Education, 23*(6), 673-696.

Kiwfo, K., Yeerum, C., Issarangkura Na Ayutthaya, P., Kesonkan, K., Suteerapataranon, S., Panitsupakamol, P., ... & Grudpan, K. (2021). Sustainable Education with Local-Wisdom Based Natural Reagent for Green Chemical Analysis with a Smart Device: Experiences in Thailand. *Sustainability, 13*(20), 11147.

KPMG Global Energy Institute (2014) Asia Pacific's Petrochemical Industry: A tale of Contrasting Regions .

Li, B., & Eilks, I. (2021). A systematic review of the green and sustainable chemistry education research literature in mainland China. *Sustainable Chemistry and Pharmacy, 21*, 100446.

Listyarini, R. V. (2019). Promoting sustainability in undergraduate program: Students' perception in green chemistry course. *International Journal of Indonesian Education and Teaching, 3*(1), 67-79.

Listyarini, R. V., Pamenang, F. D. N., Harta, J., Wijayanti, L. W., Asy'ari, M., & Lee, W. (2019). The integration of green chemistry principles into small-scale chemistry practicum for senior high school students. *Jurnal Pendidikan IPA Indonesia, 8*(3), 371-378.

Ma, J., & Shengli, H. (2020). Evaluating Chinese Secondary School Students' Understanding of Green Chemistry. *Science Education International, 31*(2), 209-219

Mafumiko, F., Voogt, J., & Van den Akker, J. (2013). Design and Evaluation of Micro-Scale Chemis-try Experimentation in Tanzanian Schools. *Ed-ucational design research–Part B: Illustrative cases*, 581-600.

Matus, K. J., Xiao, X., & Zimmerman, J. B. (2012). Green chemistry and green engineering in China: drivers, policies, and barriers to innovation. *Journal of Cleaner Production, 32*, 193-203..

Mahaffy, P. G., Krief, A., Hopf, H., Mehta, G., & Matlin, S. A. (2018). Reorienting chemistry education through systems thinking. *Nature Reviews Chemistry, 2*(4)

Marteel-Parrish, A., & Newcity, K. M. (2017). Highlights of the Impacts of Green and Sustainable Chemistry on Industry, Academia, and Society in the USA. *Johnson Matthey Technology Review, 61*(3)

Miziołek, T., & Feder-Sempach, E. (2019). Tracking ability of exchange-traded funds. Evidence from Emerging Markets Equity ETFs. *Bank i Kredyt, 50*(3), 221-248.

Nurbaity, R. Y., & Ridwan, A. (2016). Integration of green chemistry approach in teacher education program for developing awareness of environmental sustainability. In *ASEAN Comparative Education Research Network Conference*.

OECD (2021). EMnet Working Group on Green Economy in Emerging Markets Green Economy and Energy Transition in Emerging Markets 2021. *OECD Emerging Markets Network*.

Płotka-Wasylka, J., Kurowska-Susdorf, A., Sajid, M., de la Guardia, M., Namieśnik, J., & Tobiszewski, M. (2018). Green chemistry in higher education: state of the art, challenges, and future trends. *ChemSusChem, 11*(17), 2845-2858.

Reniers, G., & Cozzani, V. (Eds.). (2013). Domino effects in the process industries: modeling, prevention, and managing. Newnes.

Santos, R. G., & Guidote Jr, A. M. (2015). The green chemistry and Filipino approach to high school experiments in Saint Paul College Pasig.

Tantayanon, S. (2015). Achieving Work-Family Harmony: My Experiences as a Chemist and a Housewife. In Jobs, Collaborations, and Women Leaders in the Global Chemistry Enterprise (pp. 391-407). American Chemical Society.

Tantayanon, K. Doxsee, K. M., Nuntasri, D., and Niedbala, J. C., (2011). Distance Learning in Green Chemistry. *Chemistry International--Newsmagazine for IUPAC, 33*(4)

Toronto, C. E., & Remington, R. (Eds.). (2020). A step-by-step guide to conducting an integrative review. Cham, Switzterland: Springer International Publishing.

US EPA: "Green Chemistry", 2021, available at: https://www.epa.gov/greenchemistry (Accessed December 2021).

Walker, J. P., & Sampson, V. (2013). Learning to argue and arguing to learn: Argument-driven inquiry as a way to help undergraduate chemistry students learn how to construct arguments and engage in argumentation during a laboratory course. *Journal of Research in Science Teaching, 50*(5), 561-596.

Wang, J., Kumar, S., & Chang, S. F. (2010). Sequential projection learning for hashing with compact codes.

Wang, M. Y., Li, X. Y., & He, L. N. (2018). Green chemistry education and activity in China. *Current Opinion in Green and Sustainable Chemistry, 13*, 123-129.

Wang, A., Chen, M., & Jeronen, E. (2020) Green Chemistry Education.

Zhou, N. (2019). The development of microscale laboratory (ML) in China. *African Journal of Chemical Education, 9*(3), 15.