Institut für Didaktik der Naturwissenschaften - Abteilung Chemiedidaktik

Education for Sustainable Development in Chinese Secondary Chemistry Education under Consideration of Confucian Ecological Ethics

DISSERTATION

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By

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子曰：“不愤不启，不悱不发。举一隅不以三隅反，则不复也。”
——《论语·述而》

Confucius said, “*I do not open up the truth to one who is not eager to get knowledge, nor help out any one who is not anxious to explain himself. When I have presented one corner of a subject to any one, and he can not from it learn the other three, I do not repeat my lesson.*” (*The Analects*, 7:8, translated by Legge, 1861, p.61)

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Baoyu Li 李宝玉, University of Bremen, Bremen, June 2023.

OVERVIEW

This dissertation is a cumulative doctoral work. It contains four international journal articles. Two published articles are literature reviews, while the other two articles under review are case studies. This dissertation work focuses on the inclusion of Confucian ecological ethics in chemistry education for sustainability at Chinese secondary schools to promote education for sustainable development, for devoting to the cultural aspects of scientific literacy. In detail, this research aims at developing and implementing teaching interventions about fusing Confucian ecological ethics into chemistry education for sustainability in mainland China, with a socio-scientific issue of disposable plastic takeout food containers use. It is based on the related literature investigations and the development of the theoretical frameworks.

The first and second journal articles portray the contexts and theoretical frameworks of this research. The first article illustrates the state of the art of chemistry education for sustainable development in mainland China by a systematic literature review based on leading international and national databases. It is that Chinese chemistry education for sustainable development was at the initial stage and lacked the related teaching models and examples; and tertiary education was better than secondary education, with more related examples and multiple instruction methods. The current Chinese high school chemistry curriculum standards underscore the societal aspect of chemistry education and nurture students' awareness of sustainable development. This further proves the meaningfulness of this research. Hence, the second journal article presents a theoretical framework for the design of the teaching interventions for integrating Confucianism into Chemistry education towards sustainability. It was developed by a systematic reflection of related academic publications in related databases on Confucianism, sustainability, and science education from a philosophical perspective. There are many connections between sustainability and Confucian ecological ethics, such as respecting nature and holistic thinking. The Confucian way of thinking and views of nature differ from the Western, and Confucian harmony with nature and humans could be beneficial for the global community.

The third and fourth journal articles describe the development and implementation of two lesson plans and thus present related practical learning examples and empirical evidence for this research. They display the integration of Confucianism into chemistry education for sustainability at Chinese upper secondary schools. The third journal article depicts a lesson plan designed based on the framework developed in the second article. It contains an introduction, learning related scientific knowledge, a role-playing debate, and a reflection, referring to the socio-scientific issue of plastic takeout food container use. It was implemented at one suburban Beijing public high school in June 2022 online, due to the Covid-19 pandemic. Two learning groups of 10^{th}-Grade students (N=79) joined the intervention. The lesson plan was evaluated by a feedback questionnaire. According to the analysis of the students' feedback questionnaire, the following results were obtained: most students were motivated to learn and satisfied with the teaching methods;

Confucianism can improve their environmental awareness; and they thought Confucian ecological ethics and sustainable development in chemistry education were interconnected.

In the last journal article, another lesson plan was designed based on the positive results of Confucianism for chemistry education for sustainability. Moreover, some researchers called for nurturing students' deep understanding of Chinese traditional cultures in chemistry classrooms. The lesson plan in the fourth journal article was designed including four phases: an introduction, understanding Confucianism and sustainability, an application with the issue of plastics use, and a reflection with a feedback questionnaire. Sixty-five 10^{th}-Grade students at an urban key public high school in Beijing participated online in this intervention in January 2023 due to the Covid-19 pandemic. The feedback questionnaires were analyzed by descriptive statistics and qualitative content analysis. Their assignments and one teacher's observation were also analyzed as references. Finally, this article found that most students were engaged in learning and satisfied with the teaching methods; the lesson made them open-minded, culturally confident, and knowledgeable of the complexities of chemical issues; and most of them acknowledged the active role of Confucian ecological ethics in chemistry education towards sustainability. In summary, this dissertation shows the sound role of Confucian ecological ethics in Chinese chemistry education towards sustainability and enriches multi-worldviews to the cultural aspects of science education.

ZUSAMMENFASSUNG

Bei dieser Dissertation handelt es sich um eine kumulative Doktorarbeit. Sie enthält vier internationale Zeitschriftenartikel. Bei zwei veröffentlichten Artikeln handelt es sich um Reviews, während es sich bei den beiden anderen Artikeln um Fallstudien handelt. Diese Dissertationsarbeit konzentriert sich auf die Einbeziehung der konfuzianischen ökologischen Ethik und Nachhaltigkeit in den Chemieunterricht an chinesischen weiterführenden Schulen, um Bildung für nachhaltige Entwicklung zu fördern und sich den kulturellen Aspekten der scientific literacy zu widmen. Im Detail zielt diese Forschung auf die Entwicklung und Umsetzung von Lehrinterventionen zur Verschmelzung der konfuzianischen ökologischen Ethik mit dem Chemieunterricht für Nachhaltigkeit auf dem chinesischen Festland am Beispiel der Problematik der sozialwissenschaftliche der Verwendung von Einweg-Lebensmittelbehältern aus Kunststoff zum Mitnehmen ab. Es basiert auf den entsprechenden Literaturrecherchen und der Entwicklung der theoretischen Rahmenbedingungen.

Der erste und der zweite Zeitschriftenartikel beschreiben die Kontexte und theoretischen Rahmenbedingungen dieser Forschung. Der erste Artikel veranschaulicht den aktuellen Forschungsstand zur Bildung für nachhaltige Entwicklung im Chemieunterricht und -studium auf dem chinesischen Festland. Hierfür wurde eine systematische Literaturrecherche auf der Grundlage relevanter internationaler und nationaler Datenbanken durchgeführt. Es zeigte sich, dass sich die chinesische Chemiebildung für nachhaltige Entwicklung noch im Anfangsstadium befindet, und es an entsprechenden Lehrmodellen und Beispielen mangelt. Der Tertiärbereich ist hierbei besser aufgestellt als der Sekundarbereich, da es mehr verwandte Beispiele und vielfältigere Lehrmethoden gab. Die aktuellen chinesischen Lehrplanstandards für Chemie an weiterführenden Schulen unterstreichen zudem den gesellschaftlichen Aspekt des Chemieunterrichts und fordern, das Bewusstsein der Lernenden für nachhaltige Entwicklung zu fördern. Dies ist ein weiteres Zeichen für die Notwendigkeit dieser Forschung. Daher stellt der zweite Zeitschriftenartikel einen theoretischen Rahmen für die Gestaltung von Lehrinterventionen zur Implementierung des Konfuzianismus und der Nachhaltigkeitsbildung in den Chemieunterricht vor. Dieser wurde durch eine systematische Reflexion wissenschaftlicher Veröffentlichungen in den Datenbanken zu Konfuzianismus, Nachhaltigkeit und naturwissenschaftlicher Bildung aus philosophischer Perspektive entwickelt. Es gibt viele Verbindungen zwischen Nachhaltigkeit und konfuzianischer ökologischer Ethik, wie zum Beispiel Respekt vor der Natur und ganzheitliches Denken. Die konfuzianische Denkweise und Sicht auf die Natur unterscheidet sich von der westlichen und die konfuzianische Harmonie mit der Natur und den Menschen könnte der weltweit an Relevant gewinnen.

Im dritten und vierten Zeitschriftenartikel werden zwei Unterrichtsbeispiele entwickelt und umgesetzt, um entsprechende praktische Lernbeispiele und Beweise für diese Forschung vorzustellen. Sie integrierten den Konfuzianismus und Bildung für nachhaltige Entwicklung in den Chemieunterricht an chinesischen Schulen. Der dritte Zeitschriftenartikel stellt einen Unterrichtsverlaufsplan vor, der auf dem im zweiten Artikel entwickelten theoretischen Rahmen basierte. Die geplante Stunde enthält eine Einführung in das Thema, eine Erarbeitung entsprechender wissenschaftlicher Erkenntnisse, ein Rollenspiel und eine Reflexion, die sich auf das Thema der Verwendung von Lebensmittelbehältern aus Kunststoff zum Mitnehmen bezieht. Aufgrund der Covid-19-Pandemie wurde es an einer Oberschule in einem Vorort von Peking online im Juni 2022 umgesetzt. Zwei Lerngruppen von Lernenden der 10. Klasse (N=79) nahmen an der Intervention teil. Der Unterricht wurde anhand eines Feedback-Fragebogens evaluiert. Die Analyse der Fragebögen der Lernenden ergaben Folgendes: Die meisten Lernenden zeigten eine Lernmotivation und waren mit den Lehrmethoden zufrieden; Konfuzianismus kann ihr Umweltbewusstsein verbessern; sie glauben, dass konfuzianische ökologische Ethik und nachhaltige Entwicklung im Chemieunterricht miteinander verbunden seien.

Im letzten Zeitschriftenartikel wird ein weiterer Unterrichtsverlaufsplan basierend auf den positiven Ergebnissen des Konfuzianismus für den Chemieunterricht für Nachhaltigkeit weiterentwickelt. Darüber hinaus forderten einige Forscher:innen, im Chemieunterricht ein tiefes Verständnis der Schüler:innen für die traditionelle chinesische Kultur zu fördern. Der Verlaufsplan im vierten Zeitschriftenartikel wurde basierend auf vier Phasen entworfen: einer Einführung, dem Verständnis von Konfuzianismus und Nachhaltigkeit, einer Anwendung zum Thema Kunststoffnutzung und einer Reflexion mit einem Feedback-Fragebogen. Aufgrund der Covid-19-Pandemie nahmen 65 Schüler der 10. Klasse einer öffentlichen Oberschule in Peking online im Januar 2023 an dieser Intervention teil. Die Feedback-Fragebögen wurden mittels deskriptiver Statistik und qualitativer Inhaltsanalyse ausgewertet. Die Lösung der Aufgaben und die Beobachtung einer Lehrkraft dienten zudem als Referenz. Es wurde festgestellt, dass die meisten Lernenden mit dem Lernen beschäftigt und mit den Lehrmethoden zufrieden waren; durch die Lernintervention wurden sie aufgeschlossen, kulturell selbstbewusst und lernten die Komplexität chemischer Probleme kennen. Die meisten von ihnen erkannten zudem die aktive Rolle der konfuzianischen ökologischen Ethik im Chemieunterricht für Nachhaltigkeit an. Zusammenfassend zeigt diese Dissertation die wichtige Rolle der konfuzianischen ökologischen Ethik im chinesischen Chemieunterricht für Nachhaltigkeit auf und bereichert so die weltanschaulichen Aspekte im naturwissenschaftlichen Unterricht um nationale kulturellen Aspekte.

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1 Introduction

Scientific and technological knowledge facilitates many societies into industrialization with the improvement of people's lives and social development. Otherwise, there are many side effects, e.g., climate change, environmental pollution, and natural resource depletion. Western countries started to think about restricting the development of societies. They widely waved environmental movements since the publication of *Silent Spring* (Carson, 1962) reported that the pesticide of dichloro-diphenyl-trichloroethane (DDT) heavily influenced the ecological systems in the 1960s (Khondker, 2015). Later, the United Nations (UN, 1972) first addressed the human environment and advocated all countries together to sustain an inhabitable environment for people. The most remarkable event was the concept of sustainable development (or sustainability) coined in *the Brundtland Report* by the UN (1987). It means "development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs" (UN, 1987, para. 1). Although there are many definitions of sustainable development raised during the last three decades, the essential ideas are consistent and concern the balancing development of society, ecology, and economy for a sustainable future (Burmeister et al., 2012; Dobson, 1996).

1.1 Education for sustainable development

To obtain the overarching implementation of sustainable development, UNCED (1992) called for fulfilling all kinds of settings of education to promote sustainable development. It was named "Education for sustainable development (ESD)", for fostering present and future generations equipped with related knowledge and skill, informed decision-making abilities, awareness, and actions regarding sustainable development. A series of policies were followed, released by the UN, to forward ESD (Eilks, 2015). For instance, the current policy in *Agenda 2030* stressed, "By 2030, ensure that all learners acquire the knowledge and skills needed to promote sustainable development, including, among others, through education for sustainable development and sustainable lifestyles…" (Goal 4.7: UN, 2015, p. 17).

ESD is inter-disciplinary, values-centered, and locally relevant, and emphasizes critical thinking, systems thinking, problem-solving, and decision-making abilities, through diverse instruction methods, in the globalization era (Burmeister et al., 2012; Mahaffy et al., 2018; Wiek et al., 2011). It also brings the growing interest in scientific research concerning ESD during the last few decades, especially in science education or chemistry education, in Western societies (e.g., Eilks, 2015; Hofstein et al., 2011; Jegstad & Sinnes, 2015; Obare et al., 2020).

1.2 Science education for sustainability

School science or chemistry education is essential to promote ESD, regarding teaching and learning of and about science and its application in society, for preparing future citizens and scientists or related experts (Hofstein et al., 2011). Traditionally, science education for sustainability (or science education for ESD) stresses scientific research achieving environmental education based on Western reductionism (Herranen et al.,2021; McBeath et al., 2014). Science is part of culture, and traditional cultures are recommended to concern in science education in non-western societies (Ogawa, 1989). It enriches values-oriented, locally wisdom-concerned, or multi-worldview approaches (Albe, 2013; Murray, 2015; Zidny et al., 2020) through science education for a sustainable future and social transformation.

Science education is the most predominant enabler in promoting ESD and dealing with environmental issues. ESD also promotes modern science education as a more holistic education of an individual in epistemological, socio-emotional, and behavioral aspects (Yang, 2004). There are some mainstream models developed for science education for ESD, e.g., socio-scientific issues (SSI)-based science instruction (Burmeister et al., 2012; Simonneaux & Simonneaux, 2012; Juntunen & Aksela, 2014), contextualized science education (Bencze et al., 2020), relevant science education (Stuckey et al., 2013), etc.

1.3 Social-scientific issues (SSI) based science education

SSI-based science education brings controversial, societal issues concerning scientific knowledge into science classrooms. It possesses authenticity, relevance, and controversy, related to science and technology (Marks & Eilks, 2009). In other words, it can bring open discussion and evaluation of related societal issues, connect students' daily lives, and learn scientific and technological knowledge towards ESD. SSI-based science education also can facilitate the full implementation of scientific literacy by training present and future generations with scientific knowledge and related abilities and skills, and appropriate decision-making ability, values, and behaviors for a sustainable and better future (Burmeister et al., 2012; Juntunen & Aksela, 2014; Sadler, 2011; Sjöström & Eilks, 2018).

1.4 Confucianism

As mentioned above, culture, which is specific patterns of thinking and behaviors within a group of people, should be concerned in science education of non-western societies, such as the traditional views of nature and ways of thinking (Ogawa, 1986). Nowadays, Confucianism is still one of the most influential cultures in East Asia, such as mainland China, Hong Kong, Macao, Taiwan, Korea, Japan, Vietnam, Malaysia, and Singapore (Li et al., 2022). It was founded by Chinese educator, politician, and philosopher Confucius (551-479 BC). Confucius advocates people with ethical virtues, values, and proper behaviors embedded in all kinds of areas for a stable society (Lai, 2008).

Confucian ethics among humans was further extended into the natural environment by Neo-Confucianists in Song and Ming Dynasties. New Confucianists of modern societies tried to introduce Confucianism to the global community to deal with the dilemma of industrialization since the last century. Confucian views of nature are unique and metaphysical, the Unity of Nature and Humans (*tian ren he yi*), compared to separate Western perspectives in science. Confucian ecological ethics encouraged humans to harmoniously and peacefully live with all creatures and things in nature (Tu, 2001; Tucker, 1991). Confucian education advises individuals to constantly practice being noble (*junzi*), reaching Confucian virtues through self-cultivation (Brindley, 2011; Li et al., 2022). These match with the goals of ESD and might contribute to promoting ESD in science classrooms in the societies of East Asia (Chen, 2019; Kim & Roth, 2008; Sjöström, 2018), such as mainland China.

2 Research background

China has a vast territory, a long history, the largest population, and the rapid growth of the economy and the development of society during the last four decades. Similarly, it also faces environmental issues as the side effects of the fast development of industrialization over a few decades. As mentioned above, science education plays a pivotal role in conflicting these issues, school science education in particular. "*Rejuvenating the country through science and education*" has been regarded as the national strategy in China since 1996 (The History of the People's Republic of China, 2023). Chinese school science education also has gained international attention, for students' high achievements on international school science assessments since the late 2000s, for example, *the Trends in International Mathematics and Science Study (TIMSS)* and *the Programme for International Student Assessment (PISA)* (Cheng & Wan, 2016). Nationwide, the gross enrollment ratio of upper secondary education had increased to 91.6% in 2022 in China (the Ministry of Education of the People's Republic of China [MOE], 2023).

Science curriculum standards for Chinese secondary schools have shifted from knowledge and skills oriented, three dimensions of goals (knowledge and skills, procedure and methods, and emotions, attitudes, and values), to core scientific competencies during the past 40 years (Wei & Chen, 2020). As such, the current Chemistry Curriculum Standards for High Schools (the 2017 version) (MOE, 2018) first highlighted the social aspects of chemistry education (Wei, 2019). It contains five core chemistry competencies: "*macroscopic identification and microscopic analysis, changes and equilibrium, evidence-based reasoning and modeling, scientific inquiry and innovation, and scientific attitude and social responsibility*".

The fifth core competency is to nurture students with awareness of green chemistry (Anastas & Warner, 1998) and sustainable development. It delineates that students should "have awareness of sustainable development for saving energy and protecting the environment; to form an appropriate and green low-carbon lifestyle; to make correct value judgments about chemistry-related, hot social issues; to attend social practice activities about chemical issues" (MOE, 2018, p. 5). It brings a chance to promote Chinese chemistry education towards ESD at secondary schools. Secondary school students also have the strong plasticity to be nurtured with their basic scientific knowledge and thinking abilities.

Moreover, the new revision of the national secondary school chemistry curriculum standards (the 2017 version) (MOE, 2020) highlighted the integration of science and culture by absorbing excellent Chinese traditional cultures into chemistry education. It tries to enhance students' cultural confidence and dignity, and foster students with proper values and worldviews through the understanding and reflection of excellent Chinese traditional cultures. It reflects the international perspectives of modern science education, e.g., the values-oriented Vision III of scientific literacy (Sjöström & Eilks, 2018). It brought the topic of this research: Promoting Chinese secondary chemistry education towards ESD by stressing Confucianism.

3 Research objectives and framework

This research aimed at developing, implementing, and evaluating research-based innovations of chemistry education towards ESD addressing Confucian ecological ethics in Chinese secondary schools, contributing to cultural aspects of scientific literacy. The research goals also cover investigating the state of the art of Chinese chemistry education for ESD and developing the related teaching model from theoretical perspectives. The research structure, with four phases, was created, as shown in Figure 1. It started with investigating the state of the art of secondary chemistry education towards ESD in mainland China through a literature review (Li & Eilks, 2021). A systematic analysis of science education for sustainability and Confucianism was carried out to obtain a theoretical framework or model for designing related lesson plans from a philosophical perspective (Li et al., 2022). These phases were to study the contexts and develop the related theories of the lesson plan design.

The third phase, case study I (Li et al., under review), was the design, implementation, and analysis of one lesson plan with an SSI of single-use plastic takeout food containers use addressing Confucianism in Chinese secondary chemistry classrooms, based on Li et al. (2022). According to the results of Li et al. (under review), case study II (Li & Eilks, under review) was followed to underscore students' deep understanding of Confucianism and sustainability in the Chinese secondary chemistry curriculum. These two case studies provided related empirical evidence, explanations, and analysis for promoting secondary chemistry education for ESD under Confucian ecological ethics in mainland China. The following two sections provide brief descriptions of these phases of this research.

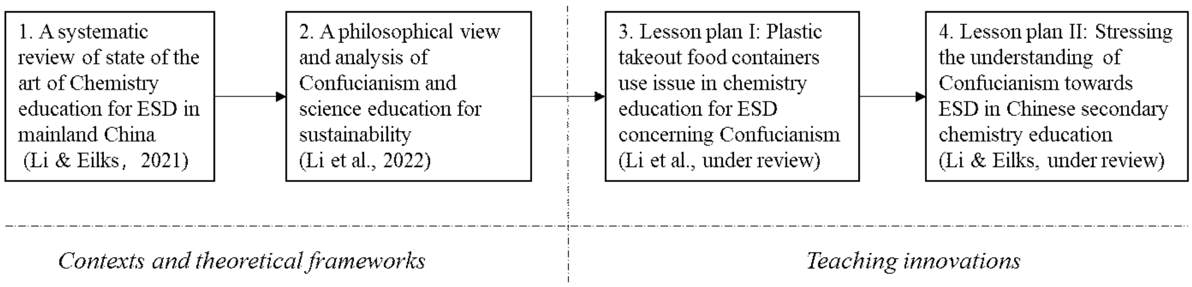

Figure 1. A framework for the development and implementation of this research

4 The groundwork for the implementation of Chinese Chemistry Education toward ESD concerning Confucianism

4.1 The state-of-the-art analysis of Chinese chemistry education for ESD

Through the screen searching of leading international and national databases, related research articles about chemistry education for ESD were gained. They were analyzed by the software of Citespace (available at the website of http://cluster.cis.drexel.edu/~cchen/citespace/) and qualitative analysis of selected articles. The followings were found.

Chemistry education research towards ESD was quite rare and in its initial stage. It only focused on introducing green chemistry and teaching strategies, and lacked related teaching models and examples. SSI-based teaching was just started in 2018. Tertiary chemistry education towards ESD was better implemented than the secondary level, with different contexts (Li & Eilks, 2021). It referred to teaching strategies, practical works, and students' awareness. However, the current chemistry curriculum standards for secondary schools (MOE, 2018), as mentioned above, stress the core competence of social responsibility to nurture students' awareness of sustainable development, which brings the chance to implement ESD in Chinese chemistry education.

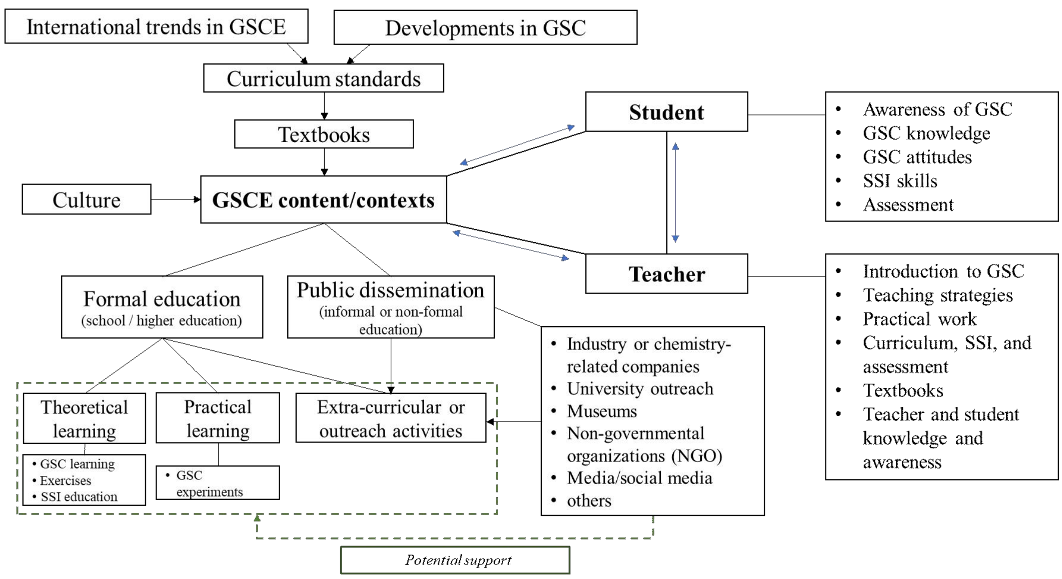

Figure. 2 A framework of chemistry education research for ESD in mainland China (Li & Eilks, 2021)

(*Note: GSC represents green and sustainable chemistry, combining the features of green chemistry and sustainable chemistry, based on two different philosophical approaches of chemistry research for ESD.*)

Based on the analysis of the selected articles, a framework for chemistry education research towards ESD in mainland China was developed to map out the areas and features shown in Figure. 2. It consists of three core components, students, teachers, and contexts and contents (Hudson & Meyer, 2011). It is to nurture related students' attitudes and skills through teachers' strategies, practical work, etc., and the public facilitation in formal, non-formal, and informal education settings. Chinese chemistry education for ESD was also influenced by the development of scientific research and the related international trend in chemistry education research for ESD. However, the cultural aspect of chemistry education towards ESD was not nearly mentioned in mainland China.

4.2 A philosophical framework of connecting Confucianism and science education for sustainability

According to the qualitative analysis of the related published literature articles about Confucianism and science education for sustainability, the contents of Confucian ecological ethics, and Confucian education and science education for sustainability were discussed, contributing to the societies of Confucian heritage culture. A framework for related research-based teaching innovations was further established in chemistry education towards ESD for Confucian societies (Li et al., 2022).

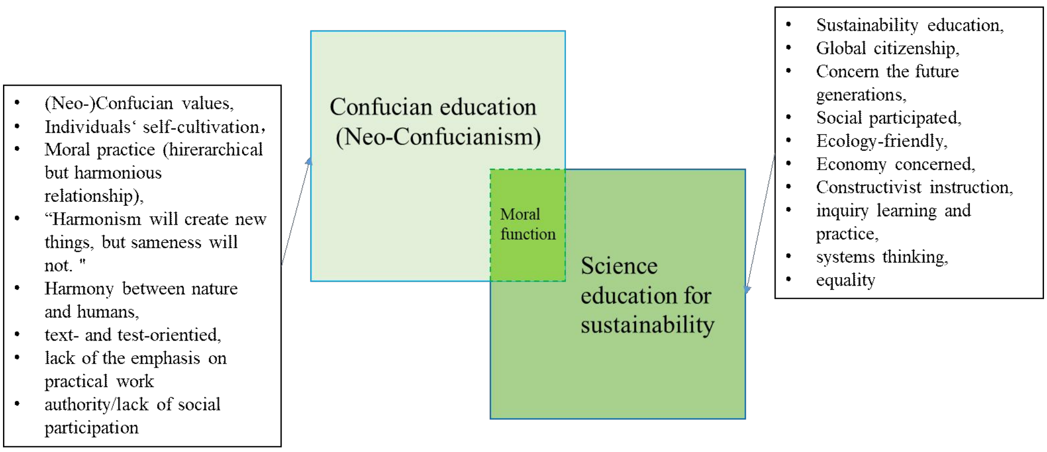

Figure. 3 The relationship between Confucian education and science education for sustainability including significant features (Li et al., 2022)

As mentioned above, the core idea of Confucian ecological ethics is the unity of nature and humans (*tian ren he yi*) means that nature and humans interact and influence each other as one system. It encourages humans to live harmoniously with all creatures in the natural environment. Confucian virtues and values related to nature are consistent with the thinking of sustainable development, for instance, benevolence to nature, harmonism among individuals, communities, and nature, rational utilization of natural resources following the patterns and principles of nature, etc. (Li et al., 2022).

Confucian education advocates versatile teachers to instruct in respect of students' abilities and needs (*yin cai shi jiao*), and thinks teaching and learning facilitate each other (*jiao xue xiang zhang*) (Huang & Asghar, 2018). It also encourages an individual to think and reflect on their learning and practice Confucian virtues or values to achieve the unity of knowing and actions (*zhi xing he yi*) to be a noble person (*junzi*) by self-cultivation (Li et al., 2022). It has a moral function as science education for ESD, shown in Figure 3. They have some different features. For example, science education for ESD is socially participated and concerns economic growth, but Confucianism advocates individual intrinsic self-cultivation to harmonism with nature from inside to outside. Confucian education is also text- and test-centered learning, compared to inquiry-based and constructivist learning in science education for ESD.

Furthermore, the framework for the design model of research-based teaching innovations was developed to promote chemistry education towards ESD by addressing Confucian ecological ethics in Confucian societies, shown in Figure 4 (Li et al., 2022). It contains teaching goals, teaching methods, contexts, students' pre-knowledge, assessment, etc. It was built based on the features of Confucian education and science education for ESD, and one leading and comparable SSI-based science education model, such as Marks and Eilks (2009). The low cultural-sensitive "(*Bildung*-centered) Didaktik analysis" model (Klafki, 2000) also was concluded for identifying contents and examples, further assisting in preparing the teaching innovations (Li et al., 2022).

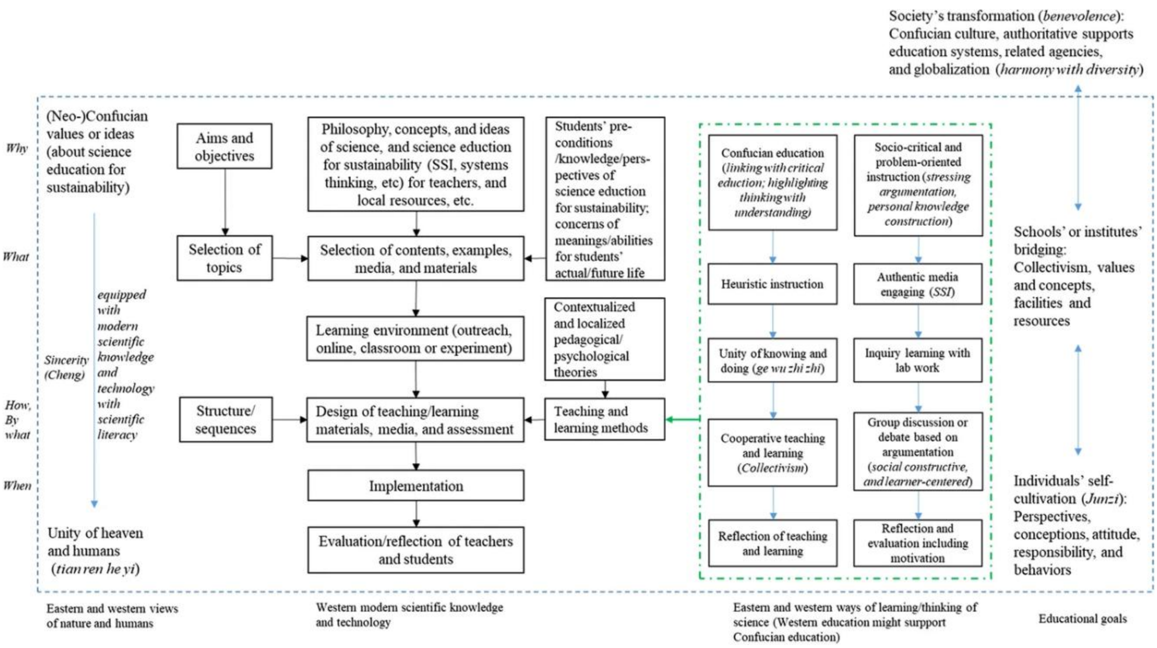

Figure 4. A framework for the implementation of science education for sustainability connecting Confucianism (Li et al., 2022)

5 The two case studies for promoting the cultural aspect of Chinese Chemistry Education towards Sustainability

The takeout food industry in mainland China has rapidly grown, bringing vast economic value and convenience to people's lives during the previous decade. However, it causes severe pollution of disposable plastic takeout food containers (Zhang & Wen, 2022). In 2020, the Chinese government released a policy banning and limiting conventional disposable plastic products in the business. It stipulated that traditional disposable plastic food containers should be reduced by 30% in takeout services in the urbanized areas in the prefecture-level cities and coastal counties (Liu et al., 2022). Biodegradable plastics, e.g., polylactic acid (PLA), are recommended as alternatives for conventional plastics, such as polypropylene (PP), popularly used in disposable takeout food containers. However, compared with PP, the total environmental impacts, high prices, and biodegradability of PLA are questionable. It draws the society's argument about whether or not to ban single-use conventional plastic food containers in takeout services in the public media. It is the topic of the related SSI in the following two research-based teaching innovations for promoting Chinese secondary chemistry education towards ESD through connecting with Confucianism. In each of the following two innovations (Li et al., under review; Li & Eilks, under review), it consists of teaching design, the implementation and methods, and findings and discussions.

5.1 Case study I: A lesson plan of plastic takeout food containers use issue in Chemistry education fusing Confucianism

5.1.1 The design of the lesson plan

This teaching intervention was designed based on the framework in Figure 4 (Li et al., 2022), with the SSI of disposable plastics used in takeout food containers. The design structure is shown in Table 1, including teaching objectives, learning methods, and online media, due to the Covid-19 pandemic. It contains an introduction, learning and inquiring scientific knowledge with practical work of PP and PLA, one role-playing debate of the plastics use issue, and a reflection with one feedback questionnaire within 195min. Confucianism was fussed at each stage. For instance, students were asked about their views of this issue after the Confucian harmony of humans and nature was mentioned in the introduction phase. The holistic thinking of the Confucian unity of nature and humans was compared with the systems thinking of ESD during the analysis of the life cycle assessment (LCA) of PP and PLA.

5.1.2 Implementation and evaluation

Seventy-nine 10th-Grade students in two groups (15-16 years old; 47 males and 32 females, each group with 39 or 40 students) joined this intervention online in chemistry classes, due to the Covid-19 pandemic, in June 2022. They are from a suburban public high school in Beijing, China. The principal of the school permitted the implementation, and the homeroom teachers took the responsibility of communicating with the students' parents.

Table 1. The structure of the lesson plan on plastics used in takeout food service

Stage	Content	Purpose	Media and learning
Introduction (45min)	• Overview • Plastics use data in takeout food service • Plastic pollution video • Plastics use policies in mainland China • A critical article on biodegradable plastics	Presenting the SSI, providing background information, and introducing the controversy	Online conference tool with collaborative learning phases, presentation, datasheet, video, article
Scientific background (90min)	Historical development of biodegradable plastics Comparison of properties between PP and PLA Synthesis of PLA experiment Degradability of PLA experiment LCA of PLA and PP food containers	Understanding the scientific background behind the use of conventional and biodegradable plastics	Online conference tool with collaborative learning phases, presentation, videos, worksheets
Debate (45min)	moderator Confucianist Chemist *(studying conventional plastics)* Biodegradable Disposable Plastic food container manufacturer Environmental organization agent Government official Restaurant *(with a takeout service)* manager	Understanding the complexity of chemistry-related SSIs, the potential role of Confucian ecological ethics for sustainability ideas, and fostering students' decision-making, argumentation, and social responsibility skills.	Online conference tool with collaborative learning phases, worksheets for role play preparation, role play introduction and with tips, evaluation rubric for the debate
Reflection (15min)	Questionnaire on students' interest, perception of relevance, and perspectives about the role of Confucian ecological ethics in science education, etc.	Reflection and assessment of students' learning and perception of the lesson plan	Wenjuanxing *(online questionnaire platform)*

The students had a basic knowledge of organic chemistry and the life of chemistry. Every five or six formed one learning group with one leader for their cooperative learning, assigned by the chemistry teacher. The intervention was taught by the author. At last, 74 students filled out the questionnaire. The feedback questionnaire consists of two open-ended questions and twelve 5-point Likert items for gaining their perceptions of the lessons and their views of the role of Confucian ecological ethics in chemistry education. They were analyzed by word cloud analysis (the website link: https://classic.wordclouds.com/) and descriptive statistics, respectively.

Figure 5. Students' feedback in the Likert items (N=74)

5.1.3 Findings and discussion

The results of the students' feedback in Likert items were shown in Figure 5. Most of the students enjoyed the learning (Items 1-3). Only 10% disagreed the lesson plan was relevant to the chemistry curriculum (Item 4). It also was reflected in Figure 6(a), the word cloud results of the students' answers to the open-ended question "*What do you think about the lesson plan?*" Most of them gave positive feedback. The most frequent answers were good, like, interesting, innovative, practical, etc. Some students also thought it was different from their previous chemistry class. They liked the debates, discussions with their classmates, the feature of daily life related, etc. For instance, one student said, "*This lesson was outstanding. It was quite different from my chemistry class before, which only focused on chemistry knowledge, rather than this with a daily-context chemistry*". It was in accordance with students' answers in Items 7-9 (around 75% agreed and less than 5% disagreed). It nurtured them with related skills, such as communication skills, and made them open-minded and knowledgeable about the complexity of SSI.

Most of the students agreed on the positive role of Confucian ecological ethics in chemistry education (75% agreed, and less than 2% disagreed in Items 10-12). They thought that there were some similarities between Confucianism and sustainability. This topic drew their attention to plastic issues and led them to more responsible attitudes and behaviors for a sustainable future. It also was reflected in their answers to the open-ended question of the relationship between Confucian ecological ethics and sustainable development in chemistry education, shown in Figure 6(b). The most frequent answers were interconnected, complement, mutual, or infiltrated. As such, one student wrote: "*I think their relationship among Confucianism, sustainable development, and chemistry learning is complementary and inseparable. Only as each step done comprehensively, can the environment be protected and better results be achieved.*"

(a) (b)

Figure 6. The word cloud results from students' feedback on the lesson plan (a) and their views about Confucianism and sustainable development for chemistry learning (b)

The findings also aligned with Kim and Roth (2008). They thought Confucianism could facilitate fostering students' environmental awareness in SSI-based instruction. The teaching intervention enriched the understanding of indigenous knowledge systems (Khupe, 2020) with empirical evidence. However, Yang et al. (2022) pointed out that Chinese secondary Chemistry classrooms lacked the integration of traditional cultures and chemistry education and called for deep understandings of traditional cultures in Chinese secondary Chemistry classrooms. It stimulated the subsequent intervention developed in the following section.

5.2 Case study II: A lesson plan of deeply learning Confucianism in Chemistry classrooms towards ESD

5.2.1 The design of the lesson plan

This teaching intervention was inspired by Park et al. (2022) and de Waard et al. (2020). It concentrated on secondary school students' deep understanding and perceptions of Confucian ecological ethics in Chinese chemistry classrooms. This teaching intervention consisted of four parts: an introduction, understandings of Confucian ecological ethics and sustainable development, an application about the plastics use issue, and a reflection with one feedback questionnaire, shown in Table 2. It is to nurture students' abilities in sustainability, such as communication skills, environmental awareness, social responsibility, normative competencies, etc. (Wiek et al., 2011). The tandem learning method was mainly used to promote students' learning. This intervention was designed based on online learning due to the Covid-19 pandemic, and multimedia were used, for example, Padlet, Tencent docs, etc. Two short edited texts about Confucian ecologic ethics and sustainability were presented with related tasks for students' deeply learning Confucian ecological ethics. The issue of plastic takeout food container use was brought to connect chemical knowledge as the application of learning Confucian ecological ethics. The questionnaire in the reflection phase was to evaluate students' experiences and perceptions of the lesson and their views of Confucian ecological ethics for chemistry education.

5.2.2 Implementation and evaluation

The intervention was tested online in one urban key public high school in Beijing in January 2023. Sixty-five 10^{th}-Grade students from four chemistry classes voluntarily joined this research after their chemistry teacher briefly introduced the lesson plan, learning method, tasks, evaluation, etc. Students learned basic chemistry knowledge concerning chemical bonding and organic chemistry. This teaching intervention got permission from the academic dean and the dean of the student management office, taking the responsibility of communicating with the students' parents. Every two students were assigned into one tandem learning group by their chemistry teacher and allowed to change based on their wills ahead of the class slightly. This intervention was taught by the author in chemistry classes. Their chemistry teacher was an observer and a teaching assistant for observing classes and helping students as needed. The chemistry teacher also filled out one observation sheet to record students' learning performance and teaching methods. Students had one week to prepare critical news articles in groups as homework.

Finally, sixty-three students voluntarily filled out the feedback questionnaire. It contained three open-ended questions and twelve 4-point Likert questions. They were analyzed by qualitative content analysis based on Mayring (2014) and descriptive statistics, respectively. Two raters carried out two rounds of analyzing students' answers to the open-ended questions in the questionnaire. A category system of the students' answers was inductively formulated through a cyclical, multi-step procedure, according to Mayring (2014). The final inter-rater reliability was almost perfect, with Cohen's kappa value of $\kappa = 0.876$. Students' assignments and the teacher's observations were also referred to interpret the feedback and teaching results.

Table 2. The structure of the teaching intervention about understanding Confucian ecological ethics in depth in Chinese secondary chemistry education

Phase	Content	Purpose	Media and learning
Introduction (10 min)	● One edited short video about plastic pollution. ● The introduction of sustainable development and Confucian ecological ethics. ● The description of the structure and contents of the course, and learning tasks, method, and evaluation.	● To prepare students to learn and take them into the topic. ● To draw students' interest in learning and know the goal of the lesson.	Video, presentation, Plenary meeting, Tencent meeting, listening and thinking
Learning about Confucianism and Sustainable development (70 min)	● The core ideas of Confucian ecological ethics and sustainable development from two short articles. ● The comparison of differences and similarities between Confucian ecological ethics and the ideas of sustainable development in one Venn diagram. ● Writing a public service advertisement for "Sustainability and Confucianism." ● The discussion of one question "*Do you think Chinese high school chemistry textbooks should properly add any Confucian ecological ethics*?"	● To learn the core ideas of sustainability and Confucianism, and compare their similarities and differences. ● To further understand sustainability and Confucianism, and the role of Confucianism in Chinese secondary chemistry education for ESD. ● To nurture students' communication skills, normative competency, argumentation, innovation and evaluation abilities, and social responsibility.	Articles, video, Tencent docs, presentation, Padlet, Tencent meeting, Plenary meeting, Tandem mode (or 1-2-all mode) cooperative learning.
Application related to one daily issue of plastic takeout food containers (40min)	● Disposable plastic takeaway food containers use issue with one consultation announcement and brief data in China ● A short video of a brief introduction of PP and PLA chemical knowledge, and biodegradable plastics. The analysis of the differences of PP and PLA, e.g., in chemical structures. ● Writing a critical news article about their position and arguments about the ban on plastics used in takeaway food containers concerning the social, cultural, and chemical aspects and ESD, and presenting the core idea about the article to the class with 1min. ● Presenting presentations, evaluating them, giving related comments, and discussing with the class.	● To bring the controversial issue of ban of plastics used in takeout food containers ● To know the chemical knowledge related to this issue ● To understand Confucian ecological ethics, sustainable development, society, and chemical knowledge by making decisions on the SSI. ● To nurture students' argumentation ability, macro-identification and micro-analysis competency, action competence, decision-making ability, and evaluation skills.	Videos, Information cards, Tencent Docs, Padlet, Tencent meeting, Plenary meeting, 1-2-all mode cooperative learning.
Reflection (15min)	● A feedback questionnaire about students' interest in this course, students' perspectives on Confucianism in Chemistry education for ESD, relevance to the chemistry curriculum, and students' learning results.	● To reflect and assess their learning and perceptions of the lesson plan.	Wenjuanxing (*online questionnaire platform*)

5.2.3 Findings and discussion

Figure 7. The results of students' Likert items in the feedback questionnaire (N=63)

The students' feedback on the Likert items was shown in Figure 7. The following findings were obtained. Firstly, most students were engaged in learning and pleased with the teaching methods (70% strongly agreed or agreed, and less than 10% disagreed in items 1-3). Most students thought this topic was relevant to them (more than 80% strongly agreed or agreed in item 6), and their communication skills or related learning methods were trained (25% strongly agreed or agreed in item 4). These aligned with their answers to the open-ended question: *What is your satisfaction with the lesson (with a scale of 0-5, from low to high), and what are the good parts or the parts to be improved?*

The average satisfaction was 4.3. Thirty-two students thought the design of the lesson was well and creative, and eighteen students mentioned the contents of the lesson were valuable. For instance, one student wrote, "*Although it was implemented online, cooperative learning of connecting chemical knowledge and environmental issues, and integrating hot, social issues [with Confucianism] were worthwhile in this lesson topic. I hope this activity can have a constant influence on future activities.* " Fourteen students suggested that more case studies or detailed information about

Confucianism and sustainability were needed to offer, or the online learning platform would be improved. The chemistry teacher also pinpointed that most students actively joined the classes, discussed the related tasks, and acknowledged the instruction methods from their classroom behaviors and expressions.

Secondly, this lesson plan also improved students' perspectives on the relationship among chemistry and other areas. Ninety-two percent agreed that chemistry education not only covered chemistry knowledge but also referred to the related areas (item 5). More than 70% of the students realized the complexity of chemical issues (item 7). It also was shown in their arguing on whether or not to add Confucian ecological ethics into the Chinese high school chemistry curriculum. Six-five percent of the students agreed, but 15% disagreed (item 9). Similarly, 39 students agreed; otherwise, 26 disagreed on one classroom assignment: "*Should Confucian ecological ethics be included in Chinese high school chemistry textbooks?"*

Lastly, most of the students agreed with the active role of Confucian ecological ethics in chemistry education towards ESD in China. They thought Confucianism could help them understand sustainable development with the local values and contexts and assist in accomplishing sustainability in chemistry education (94% strongly agree, agree, or partially agree in Items 8, 10, and 11). This lesson also improved their environmental awareness and social responsibility (81% strongly agreed or agreed, and 6% disagreed with Item 12). It also was verified on students' answers to the open-ended question: *What is the most important content you have learned from this topic of lessons?* Forty-seven students answered with learning the relationship between Confucian ecological ethics and sustainable development, which had lots of shared ideas. Twenty-six students stressed that Confucian ecological ethics was essential to environmental protection and could promote chemistry education for ESD in China. It was in line with students' answers to an open-ended question of *what is the role of Confucian ecological ethics in Chinese chemistry education (1-2 core viewpoints)*. The most frequent responses were: Confucian ecological ethics can facilitate Chinese sustainable chemistry research with Confucian values (37); it can improve people's environmental awareness and social responsibility (30); and it can connect to our real-life and increase students' learning interest, and cultural confidence (27). The chemistry teacher acknowledged the active role of Confucianism in ESD chemistry education as well.

This teaching intervention aligned with Li's (2022) findings that Confucian traditional cultures can enhance students' environmental awareness, cultural confidence, and moral practice in chemistry classrooms with a topic of learning carbon. The related findings had also been proved by Peng and Zhang (2022). They delineated that integrating Chinese traditional cultures into chemistry classrooms can increase students' learning interests, make them open-minded and foster them with proper values in a topic of learning sulfur. The following was found, compared with case study I in section 5.1 (Li et al., under review). Higher percentages of students were motivated to learn and appreciated the positive function of Confucian ecological ethics in chemistry education for sustainability in this intervention.

6 Summary

Science educators (Murray, 2015; Ogawa, 1986; 1989) advocated that traditional cultures should be included in the science education of non-western societies, such as mainland China. Furthermore, cultural aspects of science education were highlighted to promote ESD to solve environmental issues (Murray, 2015; Sjöström & Eilks, 2018), especially in school science or chemistry education. Confucian ecological ethics was discussed to have the potential to contribute to ESD in science classrooms of East Asian societies, for example, by stressing the harmony between nature and humans (Kim & Roth, 2008; McBeath et al., 2014; Sjöström, 2018). SSI-based science education was considered as one of the most influential models to promote ESD (Bencze et al., 2020; Hofstein et al., 2011; Marks & Eilks, 2009; Simonneaux & Simonneaux, 2012).

Hence, this dissertation project aimed at developing research-based teaching interventions to foster secondary school students' related abilities about sustainability through connecting Confucian ecological ethics in Chinese chemistry classrooms. It started with investigating the contexts and building theoretical models about Chinese chemistry education towards ESD merging Confucian ecological ethics. Two related teaching interventions were designed, implemented, and evaluated in two Beijing high schools.

According to Li and Eilks (2021), chemistry education for ESD in China was still at the beginning stage and lacked teaching models and examples, especially for secondary chemistry education. However, the current high school chemistry curriculum standards (MOE, 2018) underscored sustainable development, which could increase the chances of improving secondary chemistry education towards ESD. Related research about the cultural aspects was almost absent in the academic community. However, from a philosophical view, there are many common ideas between Confucian ecological ethics and science education for sustainability (Li et al., 2022). Confucian education could also fit modern constructivist learning (Huang & Asghar, 2018; Hung, 2016). The framework for the teaching designs was developed for the inclusion of Confucianism in science education for sustainability (Li et al., 2022).

The first teaching intervention was designed based on the developed framework addressing the issue of disposable plastic takeout plastic food containers use and integrating Confucian ecological ethics in Chinese secondary chemistry classrooms. It contains practical work about PP and PLA and a role-playing debate. It was tested and evaluated online in a Beijing suburban secondary school. As stated in students' feedback questionnaire, the teaching intervention nurtured their related skills and environmental awareness. They thought Confucian ecological ethics and sustainable development in chemistry education were inter-connected, according to the analysis of their feedback questionnaire (Li et al., under review).

Furthermore, the second intervention was designed based on the sound results and invited students to immerse the contents of Confucian ecological ethics and sustainability with a chemical issue in depth online, in chemistry classrooms of one Beijing urban high school. According to their feedback questionnaire and assignments, and the teacher's observation, it was found that students' deep thinking Confucianism for chemistry education toward ESD can further enhance their understanding of sustainability in chemistry classrooms, environmental awareness, and make them more open-minded about the complexity of chemical issues, such as plastic use. Most students thought the lesson plan design was well and innovative. They recognized the positive role of Confucian ecological ethics in promoting sustainable development in Chinese chemistry classrooms. The lesson also motivated them to learn chemistry knowledge and made them cultural-confident (Li & Eilks, under review).

In conclusion, this dissertation research work provided empirical evidence to verify the active role of Confucian ecological ethics in Chemistry education for ESD in China. It further displayed, explored, and proved the substantial value of combining traditional wisdom and cultures into science education in non-western societies beyond existing research, e.g., Zidny and Eilks (2020). Confucian ecological ethics can enhance the students' environmental awareness and social responsibility with actions (Li & Eilks, under review; Li et al., under review). Most students were also convinced that Confucian ecological ethics can promote the formation of Chinese sustainable chemistry research or education (Li & Eilks, under review). It enriched the research on cultural aspects of scientific literacy with a theoretical model and practical examples. It also presented that a deep understanding of Confucianism in chemistry education can further promote students' learning and sustainability competencies and increase students' cultural confidence. The results were consistent with Peng and Zhang (2022) and Yang et al. (2022).

On the other hand, some students believed Confucianism could not be included in chemistry classes, as science and culture should be separated. It means that further discussions should be held, and related case studies should be designed to enhance students' understanding of the nature of science in the future. In-service chemistry teachers' perceptions of the inclusion of Confucianism in chemistry education for ESD should be investigated as well. Training chemistry teachers' traditional cultural awareness in chemistry education is also needed, student teachers in particular, with more developed teaching examples and materials. Additionally, this research was only implemented with two case studies and a limited number of 10^{th}-Grade students in two Beijing high schools. In the future, more students in different school contexts will also be needed to participate in the research, including more case studies in various methodological approaches.

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8 Publications

All publications related to this dissertation:

1. 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.

2. Li, B., Sjöström, J., Ding, B., & Eilks, I. (2022). Education for Sustainability Meets Confucianism in Science Education. *Science & Education,* 1-30, advance article.

3. Li, B., Ding, B., & Eilks, I. (under review). A case on a lesson plan about takeout plastics use addressing Confucianism for sustainability-oriented secondary chemistry education in mainland China. Submitted to *Journal of Chemical Education*.

4. Li, B., & Eilks, I. (under review). Learning about Confucian ecological ethics to promote education for sustainable development in Chinese secondary chemistry education. Submitted to *Chemistry Teacher International*.

Declaration of the contribution of the candidate to a multi-author article/manuscript which is included as a chapter in the submitted doctoral thesis

Journal article 1:

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Contribution of the candidate in % of the total workload (up to 100% for each of the following categories):

Experimental concept and design	ca. 80%
Experimental work and/ or acquisition of (experimental) data	ca. 100%
Data analysis and interpretation	ca. 80%
Preparation of figure and table	ca. 95%
Drafting of the manuscript	ca. 80%

Journal article 2:

Li, B., Sjöström, J., Ding, B., & Eilks, I. (2022). Education for Sustainability Meets Confucianism in Science Education. *Science & Education,* 1-30, advance article.

Contribution of the candidate in % of the total workload (up to 100% for each of the following categories):

Experimental concept and design	ca. 70%
Experimental work and/ or acquisition of (experimental) data	ca. 100%
Data analysis and interpretation	ca. 80%
Preparation of figure and table	ca. 90%
Drafting of the manuscript	ca. 70%

Journal article 3:

Li, B., Ding, B., & Eilks, I. (under review). A case on a lesson plan about takeout plastics use addressing Confucianism for sustainability-oriented secondary chemistry education in mainland China. Submitted to *Journal of Chemical Education*.

Contribution of the candidate in % of the total workload (up to 100% for each of the following categories):

Experimental concept and design	ca. 70%
Experimental work and/ or acquisition of (experimental) data	ca. 100%
Data analysis and interpretation	ca. 100%
Preparation of figure and table	ca. 95%
Drafting of the manuscript	ca. 80%

Journal article 4:

Li, B., & Eilks, I. (under review). Learning about Confucian ecological ethics to promote education for sustainable development in Chinese secondary chemistry education. Submitted to *Chemistry Teacher International*.

Contribution of the candidate in % of the total workload (up to 100% for each of the following categories):

Experimental concept and design	ca. 80%
Experimental work and/ or acquisition of (experimental) data	ca. 100%
Data analysis and interpretation	ca. 80%
Preparation of figure and table	ca. 100%
Drafting of the manuscript	ca. 80%

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9 Appendix

Paper 1

A systematic review of the green and sustainable chemistry education research literature in mainland China

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Ingo Eilks

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A systematic review of the green and sustainable chemistry education research literature in mainland China

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ABSTRACT

This paper describes state-of-the-art green and sustainable chemistry education (GSCE) research in mainland China based on a systematic review of the literature. The current situation in secondary and tertiary education is explored and compared. Our analysis found that research in GSCE for secondary education basically focuses on the introduction of teaching strategies and on 'greening' required chemistry experiments. Socio-scientific issues-based teaching is initially concerning. Secondary school students' and teachers' awareness of and behaviors surrounding green chemistry are generally weak; related teaching examples or models remain a rare occurrence. In tertiary education, multiple teaching methods are reported and changes in practical work are more elaborated. Overall, GSCE research literature in mainland China is in its preliminary stage, while the currently used chemistry curriculum standards highlight the importance of GSCE at the high school level, which brings a new chance for developing GSCE in Chinese chemistry education. Some suggestions for GSCE in mainland China are derived from the results.

1. Introduction

Environmental pollution, the deterioration of ecosystems, climate change, limited natural resources, and suggested changes in energy use are a few of the unprecedented set of challenges the global community faces today, in line with the development of modern industrial civilizations. These problems are accelerating as human pressure on the earth continues to increase (United Nations Environment Program [UNEP], 2012; Zhu, 1997). The societal and economic development of more and more countries is concerned with sustainable development. The Brundtland Report by the United Nations (UN, 1987, para. 1) first defined it: "Sustainable development is development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs." Although the definition of sustainable development or sustainability has been continuously refined (Dobson, 1996; Sjöström et al., 2016), its core idea has stayed the same. It relates to keeping living conditions on earth sustainable and attempts to raise human beings' awareness of a sustainably working balance of ecological, economic, and societal development (Burmeister et al., 2012).

Education for Sustainable Development (ESD) as a worldwide political goal was first coined in Agenda 21 by the United Nations Conference on Environment and Development (UNCED, 1992). It suggested that everyone be empowered to make informed decisions. This included environmental integrity, economic viability, peace, and justice in society for both present and future generations, with an eye to respecting the many facets of diversity. To build a more sustainable world, the United Nations Educational, Scientific and Cultural Organization (UNESCO, 2002) declared the decade of 2005–2014 as the Decade of Education for Sustainable Development (DESD). DESD was initiated to promote life-long learning about sustainability occurring in a wide range of settings in formal, non-formal, or informal contexts and is an integral part of quality education (UNESCO, 2005, 2014, 2016). This view was recently forwarded into *the* Agenda 2030 where the United Nations (UN) suggested: "By 2030, ensure that all learners acquire the knowledge and skills needed to promote sustainable development, including, among others, through education for sustainable development and sustainable lifestyles …" (see Goal 4.7: UN, 2015, p. 17).

The key role ESD plays in addressing sustainable development is to pave the way for a more sustainable future (Pauw et al., 2015). ESD is as an enabler for sustainable development. It simultaneously boosts educational innovation and involves all levels and areas of education in general (UNESCO, 2012, 2014) and in chemistry education in particular (Burmeister et al., 2012). Chemistry education plays an important role

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in ESD because chemistry is closely related to modern industry, which seeks more sustainable products and production processes in every part of people's lives (Hofstein and Kesner, 2006). One answer to the many challenges faced by sustainable development is the concept of green and sustainable chemistry. This idea addresses a changed philosophy of how to apply chemistry and how to develop more sustainable processes and products (UNEP, 2019). Since the application of chemistry is one of the suggestions for change, we must also look at the question of how chemistry is taught and learned at the secondary and tertiary educational levels (UNEP, 2019). Since the ideas of green and sustainable chemistry are quite new, a logical first question arises: What does the state-of-the-art in the chemistry education literature in mainland China concerning green and sustainable chemistry education actually look like as it can be derived from published research and practice? This paper represents an analytical review of the current literature, and intends to identify the present situation and trends in green and sustainable chemistry education as it can be identified from the literature. It goes beyond this analysis to claim mapping each detail of research and common practices in mainland China concerning green and sustainable chemistry education, and it only can map a picture and identify trends from published research (under inclusion of published practical contributions).

1.1. Green and sustainable Chemistry Education

The terms green chemistry and sustainable chemistry were introduced into chemistry in the 1990s. Since then these terms and their associated concepts have been under constant debate and with continual development (Centi and Perathoner, 2009; UNEP, 2019). Although the general ideas behind both terms seem to be quite clear, there are varying interpretations in detail (Zuin et al., 2021). This section seeks to clarify the terms as being used in this review. It does not claim to provide the correct interpretation, but it does provide one potential interpretation, which is used further in this paper.

1.1.1. Green chemistry

In the 1990s, a new idea for changing chemistry practices emerged in the USA, which was proposed by Paul Anastas and John Warner: "Green chemistry" (Anastas and Warner, 1998). The term "green chemistry" has spread outwards from the United States and is still the most-used term in English-speaking countries for chemistry viewed in terms of sustainability. The main idea of green chemistry is incorporated in 12 principles aimed to reduce or eliminate risks, resource consumption and the generation of hazardous substances during the design, manufacture, and application of chemical products (Anastas and Warner, 1998). These principles were suggested to serve as the core for future chemistry by integrating sustainability into chemistry and its innovations (Manley et al., 2008). Green chemistry searches for innovative scientific solutions for industrial production and real-world environmental problems (Karpudewan et al., 2011). Therefore, future scientists should be equipped with sufficient knowledge of green chemistry to support sustainable development (Cummings, 2013; UNEP, 2019).

1.1.2. Sustainable chemistry

Around the time green chemistry emerged in the USA, the term "sustainable chemistry" was coined by the Organization for Economic Co-operation and Development (OECD). The term became widely used in Europe (Carra, 1999; Hutzinger, 1999). Sustainable chemistry is described as:

> … a scientific concept that seeks to improve the efficiency with which natural resources are used to meet human needs for chemical products and services. Sustainable chemistry encompasses the design, manufacture and use of efficient, effective, safe, and more environmentally benign chemical products and processes. (OECD, 2020, para. 3)

Sustainable chemistry highlights minimizing pollution risks during chemical production. It also attempts to bring processes to a sustainable level by simultaneously looking at the aspects of ecological friendliness, economic growth, and overall quality of life (Centi and Perathoner, 2003). Sustainability also introduces innovation into the design of new chemicals, production processes, and technologies (OECD, 2020). Sustainable chemistry is seen to differ from green chemistry and is described as:

> … the maintenance and continuation of an ecologically-sound development whereas Green Chemistry focuses on the design, manufacture, and use of chemicals and chemical processes that have little or no pollution potential or environmental risk and are both economically and technologically feasible. (Hutzinger, 1999, p. 123)

Sustainable chemistry in its original interpretation views chemistry's contribution to sustainability as more than just green chemistry (Cummings, 2013). Both concepts, however, form a new philosophy of chemistry with different traditions (Centi and Perathoner, 2009). That is why both traditions were integrated and the term "Green and Sustainable Chemistry (GSC)" was proposed (Eilks and Zuin, 2018a). This represents an eco-reflective way of performing chemistry which is embedded in society (Eilks et al., 2017).

1.1.3. Green and sustainable chemistry education (GSCE)

Green and sustainable chemistry education (GSCE) incorporates the principles, ideas, and contents of GSC into chemistry education (UNEP, 2019). GSCE aims to design suitable options which incorporate GSC thinking into all broader educational areas - curriculum development, teaching, learning, and outreach. This stretches across the spectrum from in-class activities to laboratory experiments and the dissemination of GSC information to the public (Wang et al., 2018). It is increasingly important that chemistry curricula include GSC ideas, starting at the secondary schooling level (Burmeister et al., 2012). It is here where students start to develop a profound background of and opinions about chemistry. It has also been suggested that students should develop their thinking abilities with a strong plasticity for a more sustainable future (Caruana, 2015).

Studies have shown that GSCE courses can enhance students' critical thinking, problem-solving, and communicative skills. This is necessary to understand sustainable development both locally and globally (Parrish, 2007). Students felt empowered to address environmental problems and stated that GSCE had boosted their interest and motivation to learn chemistry. They were particularly interested in the practical side of GSC and had developed a more positive view of chemistry (Caruana, 2015; Haack et al., 2005). It is, however, that there still is debate whether GSCE should be concentrated or even restricted to certain courses and programs, or whether it should permeate all domains of teaching and learning chemistry (Zuin et al., 2021). We suggest the latter, or even the latter combined with additional learning opportunities on the philosophy behind GSCE.

GSCE has also been suggested as an excellent way to attract bright students to chemistry professions (Anastas and Beach, 2009). Sustainability offers a context for learning chemistry which is rich in possibilities that connect with students (Eilks and Hofstein, 2014). This includes both their personal interests and priorities, and aids with the challenges they will later face as they enter society, first as adolescents, then as adults (Fischer, 2012). As one way to introduce GSCE in secondary chemistry education, the concepts of relevance and socio-scientific issues (SSI) have previously been emphasized (Stuckey et al., 2013). 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 (e.g., Mahaffy et al., 2018). SSIs are connected to social aspects comprised of political, economic, ethical, and humanistic factors (Klosterman et al., 2011). SSIs have already increasingly become a prominent factor in contemporary chemistry education (see the overviews, e.g., in Eilks and Rauch, 2012; Eilks and Zuin, 2018b; Obare et al., 2020; Zuin and Mammino, 2015) and systems thinking was suggested a central skill for coping with them, e.g., by IUPAC (2017).

The role GSC plays is maintaining the current standard of living, while simultaneously bettering the economy towards a more sustainable future (Burmeister and Eilks, 2012). Burmeister et al. (2012) identified four models for implementing GSCE in formal education. These include: *(1) The adoption of green chemistry principles into science education laboratory work; (2) The addition of sustainability strategies as content in chemistry education; (3) The inclusion of SSI as contexts for guiding chemistry teaching and learning; and (4) Applications of sustainable chemistry as a part of ESD-driven institutional development.* Furthermore, Jegstad and Sinnes (2015) have modified Burmeister et al.'s (2012) original model. They have suggested a refined model for planning GSCE. This is represented by five ellipses which encompass five different categories (Fig. 1) ranging from chemistry content knowledge at the core to ESD employed in the practice of chemistry education. The categories represent different aspects of a complex whole and partly overlap to achieve a holistic perspective of GSCE.

2. Background for GSCE in the case of mainland China

2.1. The international background of GSCE

In 1996, the United States Environmental Protection Agency (EPA, 2017) started the annual Presidential Green Chemistry Challenge Awards in order to promote green chemistry innovation in academia and industry. There were 109 winners in the first 21 years. The winning technologies eliminated roughly 17 billion pounds of hazardous chemicals and solvents in the United States. This award program has since been replicated in other nations, including the European Sustainable Chemistry Award created by the European Union. Several peer-reviewed journals centering around GSC have also been established, such as *ACS Sustainable Chemistry & Engineering*, *ChemSusChem*, *Green Chemistry* or *Sustaibale Chemistry and Pharmacy*. These publications have widely advanced the development of GSC research (Chanshetti, 2014; Manley et al., 2008).

Many GSCE research programs were explored for secondary education based on outreach efforts by college students, educators, scientists, and organizations in the United States. Examples include the *Green Chemistry Education Network* (GCEdNet, 2020) launched by Gordon College, the non-profit organization *Beyond Benign* (2020), and the *Green Chemistry Institute* of the American Chemical Society (ACS, 2020). These programs were dedicated to developing and implementing good GSCE practices, including abundant online teaching and learning resources (Anastas and Beach, 2009; Byrne, 2000; Kennedy and Chapman, 2019). Most programs also contain practical work activities built upon inquiry-based learning principles (e.g., Cannon et al., 2020; Duangpummet et al., 2019).

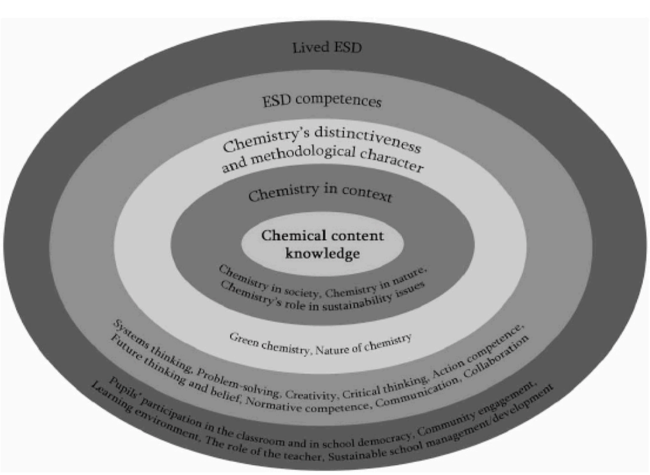

Fig. 1. A model for ESD in chemistry education suggesting chemical knowledge to be embedded into context, scientific methodology, sustainability competencies and lived ESD (Jegstad and Sinnes, 2015).

In Europe, one project of the Chemistry Is All Around Network (2020), which is funded by the European Commission, provided green chemistry teaching resources including experiments to secondary schools. Other GSCE programs or research studies include Greener Industry (2020) in the United Kingdom, chemical industry case studies in Israel (Hofstein and Kesner, 2006), and environmentally-oriented chemistry experiments (Bader, 1992; Bader and Blume, 1997), models and case studies in Germany (Eilks, 2002; Linkwitz and Eilks, 2020). In Germany, one of the objectives stated in the national science standards (The Standing Conference of the Ministers of Education and Cultural Affairs of the Federal Republic of Germany [KMK], 2004) is to nurture students' ability to communicate and form ideas about science research and technology evaluation (Burmeister and Eilks, 2012). In a word, GSCE in secondary education in Western countries has begun to develop. The process is supported by university education researchers and related agencies. It is consistent with Deng's (2010) opinion that institutional and program curricula are more easily and effectively carried out than top-down implemented curricula options.

2.2. The educational policy background for GSCE for mainland China

China has begun to play a more prominent role in the global community due to its large population and rising economic growth. However, this development also entails environmental pollution problems and gradually decreasing levels of natural resources. In order to be a responsible country, China has attempted to smoothly and practically develop ESD by means of national policies (Wang et al., 2018). "China's Agenda 21" was officially drafted by the Chinese government in 1994 along the lines of Agenda 21 by the UNCED. The strategies of sustainable development and rejuvenating China through science and education have been the basic national policies for economic and social development in China since 1996 (China National People's Congress, 1996). In 1997, green chemistry was first highlighted in *the 72nd Xiangshan Science Conference* by China's Ministry of Science and Technology. The main theme was "the challenge of sustainable development to green chemistry". In 1998, the first international workshop on green chemistry in China (1st IWGC) was held by the University of Science and Technology of China (USTC). Then *Chemistry*, one of the leading Chinese chemical journals, published a special issue called *Green Chemistry and Technology*. An initial course in green chemistry at USTC was also launched (Min, 2001; Wang et al., 2018). After this, GSC research activities rapidly increased and green chemistry courses were gradually opened by more universities. These were popularized by the establishment of several research institutes and centers of green chemistry, and by the publication of several green chemistry (experiment) textbooks in China (Anastas and Kirchhoff, 2002; Cui et al., 2011; Matus et al., 2012; Tundo et al., 2000; Wang et al., 2018). GSC also profited from increased public awareness and new regulations issued by the Ministry of Environmental Protection built in 2009 (Matus et al., 2012). The Chinese Chemical Society (CCS, 2020) in cooperation with Elsevier held a big conference in Beijing called *Green China 2019:* 1st *International Green and Sustainable Chemistry Conference*. The conference summarized the latest GSC developments in 2019. This shows that the CCS started to concern itself with the Agenda 2030 goals listed by the UN.

In the 2018 Program for International Student Assessment (PISA), a representative international assessment of science study, four cities and provinces in China (Beijing, Shanghai, Jiangsu, and Zhejiang) participated and received top marks in student science performance. Chinese science education attracted international attention including its teacher-centered, textbook-dependent, and examination-oriented features with hardworking, disciplined, and teacher-relied students in the Confucian culture (Lo, 2019; Yeung, 2015). Education in grades 1–9 is compulsory in China. Upper secondary education in grades 10–12 is comprised of vocational and general education. In 2019, the graduation ratio of junior secondary school graduates was 95.5% (the Ministry of Education of the People's Republic of China [MOE], 2020). The basic education system in China is centralized by the government. Textbook publishing, teaching, learning, and assessment are all guided by the national curriculum standards of the MOE. However, Shanghai uses local curriculum standards, since it is a leading city of educational reform. The *Shanghai Secondary School Chemistry Curriculum Standards* (Shanghai Municipal Education Commission, 2004) emphasizes the utilization of ideas of green chemistry, by general, inquiry and outreach courses using multiple learning and teaching approaches. It aims to assist students to understand environmental problems and to focus on the significance of harmony between human beings and nature.

In the previous version of the *Chemistry Curriculum Standards for High Schools (experimental version)* (MOE, 2003), which is based on scientific literacy, the topic of sustainable development was mentioned and shown in some modules of chemistry content (Bodlalo et al., 2013). The current *Chemistry Curriculum Standards for High Schools (the 2017 version)* (MOE, 2018) focuses on five core competences: "macroscopic identification and microscopic analysis, changes and equilibrium, evidence-based reasoning and modeling, scientific inquiry and innovation, and scientific attitude and social responsibility". It refers to the concept of green chemistry and highlights GSCE, including related evaluation. Its stated educational goals include fostering students' awareness of green chemistry and sustainable development. They also wish to develop a deep understanding of the relationship between chemistry, society, and the environment. For the core competence of scientific attitude and social responsibility, it requires students to:

> … have awareness of sustainable development for saving energy and protecting the environment; to form an appropriate, green low-carbon and lifestyle; to make correct value judgments about chemistry-related, hot social issues; to attend social practice activities about chemical issues. (MOE, 2018, p. 5)

According to Jegstad and Sinnes (2015), the implementation of GSCE is suggested having potential to comprehensively achieve the core competences of the current chemistry curriculum standards in China.

2.3. *The place of mainland China in the international scene of GSCE research*

To get an initial overview of international GSCE research, 532 publications were identified by searches on the topics of "green chemistry education" (GCE) or "sustainable chemistry education" (SCE) taken from the Web of Science Core Collection since 1991 (results retrieved on September 3, 2020). The numbers are for our own searches and differ slightly from those published in UNEP (2019, p. 517). The search terms may have been used slightly differently than in the first study and the date of the second search was more than a year later. The overall picture remains, however, the same.

The number of papers examining these topics increased steadily over the last 20 years (Fig. 2), especially since the year 2010. This indicates that GSCE is gaining attention in the international literature. Of the identified papers, a total of twenty-one stem from China, which is in seventh place internationally in quantitative terms. This remains, however, far less than the 213 papers published in the USA and the 45 papers stemming from Germany. Compared with chemistry research about GSC, GSCE papers produced by Chinese chemistry education researchers have much less international influence and lag behind the USA and Germany. That is why this paper investigates the current state of the GSCE literature from mainland China to provide an effective and

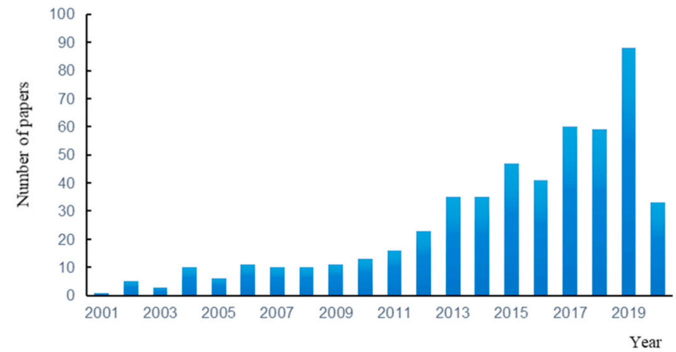

Fig. 2. The trend in the number of international leading papers published with topics concerning GCE or SCE during the last 20 years based on the Web of Science (2020 covers only the entries of the first 8 months).

feasible path or model to improve GSCE in China, especially in the case of secondary education.

3. Research questions

This literature review aims to answer the following questions.

- What is the status quo of GSCE in the chemistry education literature from mainland China?
- What are the main foci in the GSCE literature in mainland China?
- What is the connection between secondary and tertiary GSCE in mainland China?

This study focuses on mainland China. Taiwan, Hong Kong, and Macao are not included, because they have different educational traditions and different political and educational systems.

4. Method

4.1. *Data collection*

To screen the existing information about GSCE research in mainland China, we used searches from the Web of Science, Google Scholar, and ERIC (Education Resources Information Center). Search keywords were "green chemistry education", "sustainable chemistry education" and "socio-scientific issues". The latter term was considered based on the suggestion given in Burmeister et al.'s (2012) model of GSCE. It is clear, however, that not all papers identified by this search and labelled by corresponding terms were fully in line with contemporary understandings of "green chemistry education", "sustainable chemistry education" or "socio-scientific issues" from a theoretical point of view. To avoid a too great bias, all relevant papers were read and some papers were excluded "by hand" if there was an obvious mismatch with the search term intentions. The search was then reduced to papers from mainland China in these databases with an "in chin*" search and then by hand. Data was collected on October 13, 2020. The number of publications is shown in Table 1. There are some overlaps in papers of the above databases, and finally, around 20 target papers were identified (Table 1).

For issues of language use and specific local needs and concerns, English-language journals do not comprehensively necessarily represent Chinese chemistry education research and practices. Especially practical contributions might likely be more covered by local journals in China (Song et al., 2016). Thus, we explored more data in the most popular Chinese academic database: China National Knowledge Infrastructure (CNKI). Four leading journals of Chinese chemistry education in mainland China were identified: *Chinese Journal of Chemical Education* (*CJCE*), *Education in Chemistry* (*EC*), *Teaching Reference for Middle School*

Table 1
GSCE research publications in China based on international databases.

Database	Number of publications and methods	Categories of representative papers
Web of Knowledge	34 hits for "green chemistry education in chin*" OR "sustainable chemistry education in chin*", with 3 target papers in mainland China (by topics from all databases of the Web of Science); 10 hits for "socio-scientific issues in chin*", 5 hits refined by relation to chemistry education in mainland China (by topic from all databases of the Web of Science).	• Review about GSCE in China (tertiary education) Cui et al. (2011); Matus et al. (2012); Wang et al. (2018) • Curriculum analysis (secondary education) Bodlalo et al. (2013) • Practical work in teaching (tertiary education) Cai et al. (2013); Li et al. (2011); Lu et al. (2017); Xie et al. (2016); Wang et al. (2010a); Zhou et al. (2018); Zhu et al. (2008) • Teaching by lectures (tertiary education) Song et al. (2004) (exercises); Haxton and Darton (2019) • SSI (secondary education) Sternäng and Lundholm (2011; 2012); Wan and Bi (2020) • Students' awareness (secondary education)Lin (2017); Ma and Hu (2020); Zhu (2019)
Eric	288 hits for "green chemistry education" (peer-reviewed only), 7 hits refined by the location of mainland China; 120 hits for "sustainable chemistry education" (peer-reviewed only), 2 hits refined by the location of mainland China; 261 hits for "socio-scientific issues" (peer-reviewed only), 3 hits refined by relation chemistry education in mainland China	
Google Scholar	806.000 hits (excluding citations) for "green chemistry education in China", with 2 target papers by relevance; 191.000 hits (excluding citations) for "sustainable chemistry education in China", with 3 target papers by relevance; 2.210 hits (excluding citations) for "socio-scientific issues in China", 8 hits refined by relation chemistry education.	

Chemistry (*TRMSC*), and *University Chemistry* (*UC*). These journals were recognized as the first batch academic journals by the State Administration of Press, Publication, Radio, Film, and Television of the People's Republic of China in 2014. *CJCE* is a core, semimonthly journal held by CCS and Beijing Normal University since 1980. *EC* is a core, monthly journal published by East China Normal University since 1979. *TRMSC* is a popular, semimonthly journal focusing on secondary chemistry education and put out by Shaanxi Normal University since 1972. Additionally, *UC* is a popular monthly journal for chemistry teachers. It promotes tertiary chemistry education reforms and is issued by Peking University and CCS since 1986. Before 2016 it was published bimonthly.

The search keywords used in CNKI are very similar to the international search mentioned above, but reflect slight changes to match the local context. Based on the initial search in CNKI, the keyword "sustainable chemistry education" was found not to be used by Chinese chemistry educators or teachers. Therefore it was replaced by "sustainable development and chemistry education". To obtain enough target journal papers, on October 28, 2020, the authors searched CNKI for "green chemistry", "sustainable development", and "socio-scientific issues" by topic in the above-mentioned four Chinese chemistry education journals. A further search focused on "green chemistry education", "sustainable development and chemistry education", "socio-scientific issues", "green chemistry and education", and "green chemistry and chemistry education" by topic in the other Chinese academic journals of CNKI excluding the above four journals. The beginning search of the first three terms resulted in limited hits, so the keywords were supplemented by the other two terms to give more hits. The detailed data from searches using the corresponding search terms combined with the Boolean operator "OR" (retrieved on October 28, 2020) are shown in Table 2. This includes the number of target papers refined by relation to GSCE in the summaries and representative papers. Finally, a total of 1024 target papers were identified by CNKI, ranging from the year 1997–2020.

4.2. Analysis

International journal articles about GSCE research in China are quite rare. So, we decided to just present the data with illustrative examples, and to further employ them in the discussion about publications within mainland China. A broader picture of what is occurring within mainland China is based on the CNKI data. This data was subject to further analysis. Citespace 5.7. R2 software was used as a tool to identify trends in authorship, institutes, and keywords. (The software and instructions are available online at http://cluster.cis.drexel.edu/~cchen/citespace/.) The time-span setting in the Citespace is from 1997 to 2020, and every one year is as a time zone for the analysis. Due to the limited number of defined papers, the analysis started with the threshold settings of c

Table 2
GSCE research papers in CNKI.

Search terms	Journals	Number of hits (refined to GSCE)	Representative papers with categories
"green chemistry" OR "sustainable development"	*CJCE* *EC* *TRMSC* *UC*	143 (110) 68 (49) 109 (70) 54 (31)	• Introduction of international GSCE Cai (2016); Hu et al. (2003); Pei et al. (2018); Xue (1997a) • Secondary GSCE: Teaching strategies Dong and Yang (2002); Sui (2010); Zhang and Tan (2009); Ye et al. (2018) *Experiment teaching* Liu and Liu (2012); Lv (2007); Wu et al. (2011); Wu et al. (2009); Zhao (2013) *Lecture teaching* (Fan et al., 2020; Li and Fang, 2019; Sun et al., 2020; Wang and Zhang, 2019) (SSI); (Yang, 2018) (exercises) *Textbooks* Bai (2005); Yang et al. (2013) *Students' and teachers' awareness* Gu and Wang (2019); Qiu and Ma (2009); Zeng and Li (2013) • Tertiary GSCE: *Teaching strategies* Du et al. (2009); Xu et al. (2016); Xie et al. (2006); Zhang et al. (2019); Zheng and Zhou (2017) *Lecture teaching* Li and Cao (2015); Xue et al. (2016); Yu et al. (2008); Zhan et al. (2010) *Outreach activities* Chen et al. (2014); Yan et al. (2011) *Experiment teaching* Cao et al. (2010); Lin et al. (2020); Wang et al. (2010b); Yan et al. (2018) *Students' awareness* He et al. (2013); Qiao et al. (2013)
"green chemistry education" OR "sustainable development and chemistry education" OR "green chemistry and education" OR "green chemistry and chemistry education"	Others	910 (752)	
"socio-scientific issues"	*CJCE* *EC* *TRMSC* *UC* Others	3 (2) 5 (4) 8 (4) 0 (0) 35 (2)	

(citation), cc (co-citation), ccv (cosine coefficient) parameters with 1, 1, 20; 1, 1, 20; 1, 1, 20, (20 is the default number of ccv). Each paper was accounted with a comprehensive result, and then checked by settings of c, cc, increased by 1 until the produced visualization gained high centrality, valid and high modularity ($Q > 0.3$) and a weighted mean silhouette ($S > 0.5$). Other settings were default. Due to the still limited number of findings, this review should not be understood presenting a quantitative picture or research. Even if the paper reports the numbers of hits, interpretations should be understood on the level of trends and interpretations. For further qualitative interpretation, key papers were identified and inductively mapped to essential features of the teaching and learning of chemistry. From the key papers, prominent foci were identified and highlighted.

5. Findings

5.1. Trends in the GSCE research literature in mainland China

Using only international journal publications, there is only a quite limited number of papers dealing with GSCE in mainland China (see Table 1). The focus tends to mainly be on green chemistry experimental teaching, reviews of GSCE for tertiary education, SSI-based GSCE teaching, or the investigation of students' awareness of GSCE in secondary education. From the distribution of 1024 total target papers from CNKI (see Fig. 3), we can see that GSCE gradually started attracting more researchers' attention in the 2000s and stabilized around the year 2005. This differs from the continued growth of international GSCE research papers as shown by Fig. 2. The authors and their institutes in the 1024 CNKI papers were analyzed with the help of Citespace 5.7. R2 on November 2, 2020. The most productive authors in terms of publications were Xiaohua Cao and Yulong Shen, who each produced seven papers. The most productive institute in terms of numbers was Tangshan Normal University with a total of nine papers (see Table 3). Of the most productive institutes, most are normal universities. Co-authorship analysis using Citespace (the resulted clustering analysis with $Q = 0.9939$, $S = 1$) identified Xiaohua Cao as the most active writer to cooperate with others in terms of numbers. These papers make up a co-author community with Yulong Shen, Aixin Huo, and Lihua Liu. Co-institute analysis by Citespace (clustering analysis with $Q = 0.978$, $S = 1$) revealed Beijing Normal University to be the most active cooperator with other institutes or high schools in terms of publications, followed by the Jiujiang University College of Chemistry and Chemical engineering. This means that there is no single, representative community for GSCE research in China, even though some level of cooperation between authors and institutes exists.

With the Citespace threshold settings of c, cc, ccv 1, 1, 20; 1, 1, 20; 3, 3, 20, 17 resulting clusters (resulted clustering analysis with $Q = 0.6228$, $S = 0.8768$) were found in terms of keywords co-occurrence of log-likelihood ratios for the 1024 CNKI papers, including the top five terms in each cluster (see Table 4). There were many overlaps between

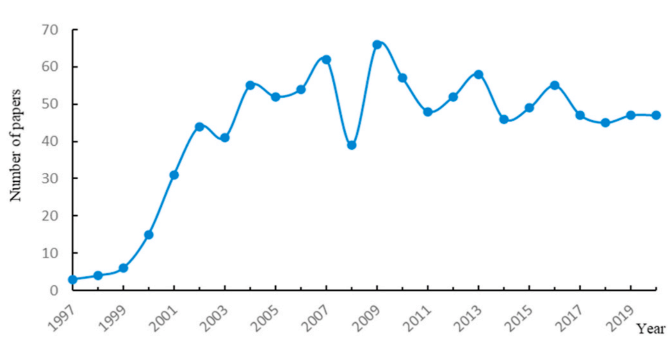

Fig. 3. The trend in published papers on GSCE from China based on CNKI for the years 1997–2020.

Table 3
Top 10 productive authors and institutes about GSCE in quantitative terms from China based on CNKI.

Rank	Authors	Count	Begin	Institutes	Count	Begin
1	Xiaohua, Cao	7	2005	Tangshan Normal university, Department of Chemistry	9	2005
2	Yulong, Shen	7	2009	Inner Mongolia Vocational College of Chemical Engineering	7	2012
3	Zhicheng, Ma	6	2003	Jiujiang University, College of Chemistry and chemical engineering	7	2009
4	Aihua, Huo	5	2003	Henan University, College of Chemistry and chemical engineering	6	2007
5	Jun, Li	5	2002	Beijing Normal University, College of Chemistry	5	2014
6	Lihua, Liu	5	2007	Huainan Normal University, Department of Chemistry and chemical engineering	5	2009
7	Guoqing, Zhong	5	2006	Wuhan University, College of Chemistry and Molecular Science	4	2010
8	Lixin, Deng	5	2001	Xinyang Normal University, College of Chemistry and chemical engineering	4	2007
9	Yong, Wu	5	1998	Anhui Normal University, College of Chemistry and Material Science	4	2009
10	Weiquan, Cai	4	2003	Hubei University, College of Xing and Zhi, Department of Biological Engineering	3	2012

the clusters. The clusters illustrate how broad any connections in teaching towards GSCE are addressed. It is clear, however, in the same time that the many clusters might imply that many papers are connected with GSCE, but are not taking its underpinnings and central aims into account with sufficient theoretical depth. The hot-button topics are organized in four categories: green chemistry experiments (teaching), the introduction of green chemistry content (education), teaching methods and reform, and chemistry textbooks. The keywords presented in Fig. 4 show that frequent keywords emerge during specific years on the time line of GSCE research in China. In the 2000s, the environmental pollution and green education were highlighted. Since 2015, green chemistry ideas were added strongly to the discussions, followed, e.g., by aspects of high school chemistry and teaching reform. SSI-based education is a new discussion area since 2018. It presents a new stage of GSCE in China.

5.2. Foci of main emphasis in the secondary GSCE academic literature in mainland China

5.2.1. Focus 1: introduction of international GSCE to mainland China

The development of GSCE for secondary chemistry education in China used the same lines as the introduction of GSCE in Western countries since the late 1990s. Xue (1997a; 1997b) first introduced green chemistry and the *Presidential Green Chemistry* Award of the

Table 4
Top-ranked clusters table of keywords co-occurrence network about GSCE research in China.

Cluster	Size	Mean (Year)	Top five terms (log-likelihood ratio)
0	114	2007	**Practice**, teaching reform, infusion, teaching, experiment
1	101	2005	**Chemistry textbook**, chemistry teaching, textbook reform, low-carbon lifestyle, medical and higher vocational education
2	88	2005	**Microscale chemistry experiment**, environmental protection, undergraduate students, pharmaceutical engineering, crystallization
3	68	2004	**Green chemistry education**, atom utilization, green chemistry, chemistry elective course, non-polar molecules
4	64	2008	**Teaching by experiments**, green chemistry course, teaching method, inorganic chemistry experiment, basic chemistry experiment
5	53	2007	**Pollution**, chemical laboratory, microscale experiments, chemistry experiments, improved experiments
6	51	2005	**Chemistry experiment teaching**, sulfur dioxide, green, broken test tubes, sustainable development
7	47	2003	**Introduction of achievements**, the Presidential Green Chemistry Award of the United States, organic solvents, atom economy, synthetic routes
8	46	2005	**Principles of green chemistry**, electrochemical industry, comprehensive exercises, outreach course
9	41	2005	**Butyl acetate**, green chemistry experiment, chemical engineering major, environmental materials, environmental protection issues
10	36	2007	**Organic chemistry experiment**, no solvent, comprehensive experiment, innovative abilities, environmentally benign chemistry
11	31	2007	**Toxic gas**, disposable syringe, sodium hydroxide solution, pipe orifice, cotton balls
12	16	2005	**Chemistry**, humanistic education, science education, psychological growth, individual motivation
13	15	2006	**Nitric acid**, oxidation number, constructing knowledge, chemical equation, Nitrogen, compound
14	12	2008	**Collaborative learning**, pharmaceutical Engineering, KAQ (Knowledge-Ability-Quality) teaching model, teaching practice, green chemistry
15	12	2004	**Organic chemistry experiment teaching**, water pump, environment knowledge, organic chemistry laboratory, green chemistry,
16	7	2008	**Low-carbon lifestyle**, chemistry, literacy, undergraduate students, higher education of engineering

United States in the publication *CJCE*. These reports were updated and other famous awards for green chemistry research from other countries were also presented (Hu et al., 2003; Pei et al., 2018). Related teaching resources such as textbooks, journals, institutes, and websites on Western GSCE were introduced as well (Cai et al., 2003). Tertiary green chemistry education from leading international universities (Shen et al., 2010; Shen and Wang, 2006) was also presented as one reference point for Chinese GSCE. Cai (2016) pointed out the measures suggested for secondary school GSCE by *Beyond Benign* of the United States. These included encouraging society agencies' participation in GCE, the construction of systemic lesson plans, enhancing the training of teachers about green chemistry, and carrying out extracurricular activities.

5.2.2. Focus 2: Teaching strategies for secondary GSCE

Several strategies for teaching GSC were identified for secondary GSCE in mainland China. One major focus is on integrating GSC into the classroom with the help of practical work by actively conducting inquiry-based learning in real contexts. Further suggestions are to provide extracurricular activities centered around GSCE, employ modern educational technologies, and utilize other societal organizations or universities (Dong and Yang, 2002; Li, 2004; Xu, 2004). Research also reported on ways to deal with the problem that teachers lack the appropriate teaching strategies for secondary GSCE and that students have low levels of GSC understanding. Ye et al. (2018) have suggested that teachers should integrate and structurally present agricultural and industrial technologies from real life using GSC with multifaceted views to motivate students' learning. Carrying out specific events or outreach activities based on GSC, such as lectures on green chemistry, poster exhibitions, green chemistry competitions, and visiting related industries or plants, has also been mentioned for GSCE (Yang et al., 2013).

5.2.3. Focus 3: Practical work

Besides teaching methods, another major focus was finding ways to change practical work. Chemistry practical work can motivate students' learning, assist students in understanding theories, and allow learners to attain practical ability with the scientific method (Woolnough and Allsop, 1985). Zhang and Tan (2009) also highlighted changes towards GSCE-based practical work: choosing different chemicals, designing green chemistry experiments based on chemistry curriculum standards and green chemistry, popularizing microscale chemistry experiments, and emphasizing the application of green chemistry experimental procedures. Other discussions have included the improvement of experimental equipment (Li, 2004), an emphasis on the whole procedure of experimental designs with environmental-friendly ideas (Dong and

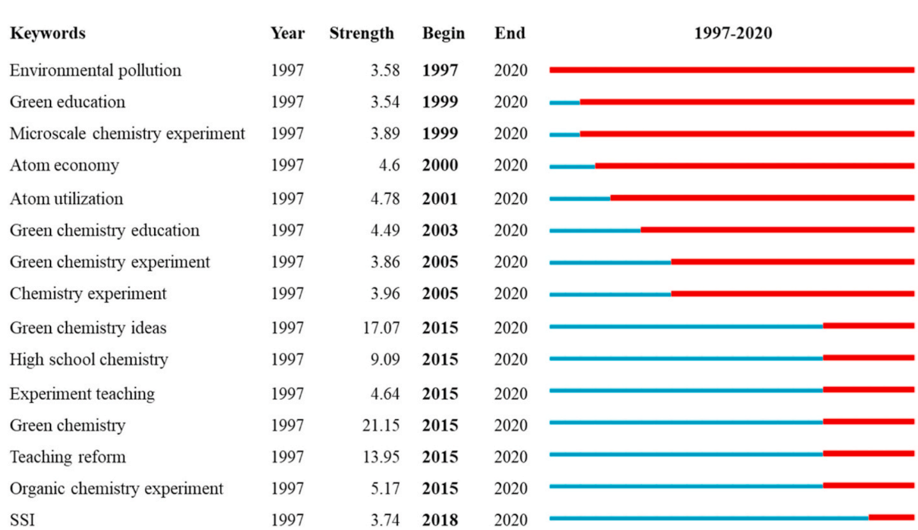

Fig. 4. Top 15 keywords with the strongest citation bursts about GSCE research in China based the database CNKI from 1997 to 2020 (red lines indicating the years the key term is highly used).

Yang, 2002), and the combination of multiple or comprehensively-designed experiments (Sui, 2010).

The improvement of green chemistry experiments plays an important part in secondary GSCE research in the acadmic papers identified from mainland China. Generally, three dimensions could be identified, namely the use of green raw materials, the implementation of microscale experiments, and the improvement of devices for existing experiments already required by textbooks or curriculum standards. Many suggestions have already been made for choosing more environmentally-benign materials. For example, using low-cost calcium oxide with a controllable experiment instead of calcium hydroxide was proposed for experiments synthesizing and examining the properties analysis of ammonia (Lv, 2007). Silica has been suggested as a replacement for the solvent chloroform in the addition reaction of ethene and bromine (Wu et al., 2011). The decomposition reaction of ammonium hydrogen carbonate as an endothermic reaction has replaced the reaction of barium hydroxide solid with ammonium chloride (Wu et al., 2009). The recycling of ammoniacal copper solution (Schweitzer's reagent) waste was employed to prepare copper (II) sulfate crystals (Liu and Liu, 2012). Microscale experiments have also been highlighted as a way to save on the cost of materials, reduce overall material consumption, and decrease environmental pollution. Examples of this include extracting and identifying iodine from kelp on spot plates (Ma and Chen, 2017), the microscale electrolysis of water, and a fuel cell made of hydrogen and oxygen in V-shaped and U-shaped devices (Zhao, 2013).

Last but not least, improved laboratory set-ups have been proposed. For example, experiments were designed to deal with toxic gases. Sealed devices were designed to carry out bleaching experiments with sulfur dioxide. They were also used for the reaction of copper with nitric acid (Sui, 2010; Yang et al., 2006). Combined devices were constructed to handle the combustion reactions of white phosphorus, red phosphorus or sulfur in air (Fu, 2013). And multifunctional devices were conceived for the production and testing of research experiments on the properties of toxic gases, such as sulfur dioxide, ammonia, and chlorine (Xie et al., 2010a, b). However, many papers still hold tightly to the traditional experiments suggested by the educational standards, instead of completely replacing them with alternatives based on arguments from GSC.

5.2.4. *Focus 4: curriculum, SSIs and assessment*

Suggestions for curriculum betterment have also been made. These argue for teachers providing more certain contexts of GSC and using appropriate teaching methods, so that their classroom teaching becomes more than content learning based on experiments. E.g., Sun et al. (2020) integrated learning about waste water treatment using a live, virtual visit to a waste water treatment plant. The visit included a live technician, a simulated experiment, and a role-playing discussion in order to foster students' awareness of green chemistry and societal responsibility. Wang and Zhang (2019) designed a course on environmental protection and green chemistry. They based their unit on content analysis of chemistry textbooks with an eye on the core competencies of scientific attitude and social responsibility. Due to the exam-orientated Chinese schooling system, green chemistry exercises have also started to play a role in green chemistry education research. College entrance examinations are one of the primary drivers of Chinese secondary education. They have always consisted of multiple choice tests or simple fill-in-the-blank answers since the year 2000 (Wang, 2001). Recently, however, some green industrial process problems were added to the list (Yang, 2018). This might compel chemistry teachers to be more concerned about teaching green chemistry ideas. Yang (2018) provided the context of coal-burning. The example combined an adapted green chemistry exercise on absorbing exhaust gas from one college entrance examination. This was tied to a class activity for grade 12, in which students carried out a group discussion to develop their core chemistry competences. The researcher found that their awareness of green chemistry had increased in the post-unit interview.

Aside from the above examples infusing GSC into content, practices and exercises, implementing SSI about GSCE is also a new concern. As we mentioned previously, research on SSI in mainland China is still in the initial stages. But recently some in-service science teachers have started paying more attention to SSI (Chen and Huang, 2020). Wan and Bi (2020) raised six potential fields of SSI topics for science teaching with the use of questionnaires among related experts. The topics included: environmental issues, safety and health, resources and energy, ecological systems, biotechnology, and new materials. All of the fields provide opportunities to be connected to GSCE. The researchers also suggested including local problems in classroom discussions. Likely candidates were traffic restrictions due to smog, the building of a sulfuric acid plant, and the operation of a paraxylene program (Chen, 2017; Fan et al., 2020; Li and Fang, 2019; Luo et al., 2020). The teaching model aims at engaging students with an SSI. This should deal with related problems in which groups of students discuss related materials. Available tools include role-playing, decision-making and reflection exercises, watching demonstrations, or carrying out related inquiry-based experiments guided by teachers. All of the documented cases showed positive results supported by accompanying reflections. Some of them were also proven to better students' argumentation abilities. Chen et al. (2019a, b) analyzed scientific risk contents in the 2012–2016 high school chemistry course plans in Jiangsu province. They found that teachers paid more attention to the contextual integration of SSIs, but lacked focus on argumentation and thinking on uncertainty and risk in science.

Due to the importance of ethical aspects in the Chinese cultural context, researchers also paid attention to students' moral views as they discussed SSIs. Sternäng and Lundholm (2011) interviewed Beijing secondary school students about climate change and found that the students have different moral standpoints about SSIs when considering individuals (self versus others). The students were concerned about economic development and affluence, and thought the environmental issues are unavoidable (Sternäng and Lundholm, 2012). However, more research about students' related abilities, such as decision-making and argumentation, and teaching interventions based on SSI is still needed. Today, most school science teachers tend to emphasize science subject knowledge which closely influences their careers. However, they may ignore the role of SSI in nurturing students' ideas about social responsibility (Albe et al., 2014).

5.2.5. *Focus 5: Textbooks*

Due to many teachers' tendency to tightly cling to the textbook, GSC ideas in textbooks are considered to be the most important and direct resource for the implementation of GSCE. As of 2000, there are three versions of chemistry textbooks used in China. There have also been two new rounds of secondary school curriculum reform: the 2003 version of scientific literacy (MOE, 2003) and the 2017 version of core competencies (MOE, 2018). According to related research, green chemistry ideas have been found in recent versions of secondary chemistry textbooks. Although the GSC content remains limited, the latter version contains more GSC content and is more multifaceted in its methods of presentation. Bai (2005) found some green chemistry content in high school chemistry textbooks used before 2003, even though the concept of green chemistry had not yet been officially introduced. Yang et al. (2013) summarized contents and topics about green chemistry in the textbooks, which were used for the 2003 curriculum reform. However, they found that green chemistry ideas tended to cluster around environmental protection. The contents shown were discrete without an outline connected to any related concepts. They also tended to appear more often in elective modules, rather than in obligatory parts of the curriculum. Chen et al. (2019a, b) concluded in their study that environmental and sustainable development issues in chemistry textbooks from mainland China remain quite limited.

5.2.6. Focus 6: Teachers and students

Although the existing GSCE investigations into secondary school teachers and students are rare, the following finding is unequivocal: Chinese teachers and students generally have only a basic understanding of GSC. Due to exam-oriented assessment and limited support, their awareness of green chemistry remains weak. Many misunderstandings about green chemistry ideas still exist, especially in rural areas (Ma and Hu, 2020; Qiu and Ma, 2009; Xia et al., 2008; Yang and He, 2008). Questionnaires of students and teachers on GSC topics, such as low-carbon lifestyle or global warming, revealed that most students had heard about the concepts from public media. Their understanding of the related concepts had not been elaborated upon sufficiently by schooling, because many teachers lack the necessary teaching strategies and resources (Lin, 2017; Zeng and Li, 2013). Gu and Wang (2019) investigated high school students' competency in green applications using questionnaires based on high school chemistry content and features of green chemistry. They found green application competences fell in line with the levels of students' academic abilities without any gender differences. Similarly, Zhu (2019) found that Chinese secondary students' attitudes, including environmental awareness, interest, and epistemological beliefs, influence their scientific competencies without gender or urban differences, based on the analysis of the student questionnaire used in PISA 2015.

5.3. Fields of main emphasis in tertiary GSCE academic literature in mainland China

Compared to secondary GSCE in China, GSCE at universities or colleges shows a much more developed form. As there are many chemistry or science majors at the different universities, institutes, and colleges, the teachers generally tend to have stronger academic backgrounds and are more concerned about research and publishing. They are more able to find and try out green chemistry experiments and to get new ideas from international communities. Tertiary GSCE in mainland China is mostly implemented in courses about green chemistry or other subsubjects of chemistry permeated by green chemistry. Green chemistry courses are usually offered as public elective courses, so they take an important role in implementing ESD at Chinese universities. This is why there is a relatively narrow range of overall foci, and papers tend to deal with the details of carrying out GSCE.

5.3.1. Focus 1: Teaching strategies in tertiary GSCE

Many universities in China have offered green chemistry courses since the early 2000s. Many teachers now have experience in this area. For elective courses of general studies at universities, Zhang et al. (2019) suggested that teachers should offer reasonable content and use multidimensional assessment in green chemistry courses. Teaching methods, such as group discussions, video-scaffolding, flipped classrooms, and lectures with certain topics are also recommended. The utilization of exercises about green chemistry can also be a valuable method (Song et al., 2004). In chemistry sub-areas, such as organic, inorganic, or medicinal chemistry, researchers suggest integrating atom economy, green reagents, green reaction conditions, and green products, core ideas of green chemistry, and green chemistry study cases into their classrooms or practical work (Du et al., 2009; Jin and Xu, 2007; Xie et al., 2006; Xu et al., 2016). Other teaching strategies are considered as well, such as engaging with the latest research results and incorporating students' daily-life problems which are related to GSC. The use of extracurricular activities is also suggested (Li, 2016; Zheng and Zhou, 2017).

The implementation of tertiary GSCE based on classroom teaching is seen as more efficient with more modern information and communication technologies and when popular education ideas are used and discussed. Case study-based teaching is proposed in green chemistry courses. For example, students can search the internet and discuss related cases before teachers explain things in the classroom. Sound results can be supported by post-learning surveys (Xue et al., 2016). Zhan et al. (2010) raised several teaching methods for infusing GSCE ideas, based on the Knowledge-Ability-Quality (KAQ) teaching model. These included using modern educational and collaboration technologies, connecting textbooks and reference books, and constructing teaching evaluation systems. Yu et al. (2008) integrated the idea of GSC in chemistry courses and guided students in building a website on environmental protection to disseminate the idea of GSC. Haxton and Darton (2019) described a course with international group discussions between Chinese and English college students, which focused on GSC topics via an Internet platform. The education of student teachers is also considered to be important. Li and Cao (2015) constructed an inquiry learning model for a green chemistry course for student teachers. This was based on writing and presenting research papers on related topics of green chemistry topics in groups. It achieved positive results in students' self-evaluation after the exercise.

Real-life contexts have provided help to students when constructing new knowledge (Rannikmäe et al., 2020). Taking advantage of local resources or contexts about GSCE can be an effective way to contribute to ESD. One case study on green chemistry about the ecological protection of Poyang Lake was implemented into classroom teaching using practical work, on-site visiting activities, and summative evaluation for undergraduate students (Yan et al., 2011). Student internships in industry and participation in research work or competitions about green chemistry were also verified as effective methods for GSCE teaching (Chen et al., 2014).

5.3.2. Focus 2: Practical work

Practical work is an important and established component of Chinese tertiary chemistry education. It is usually implemented through separate laboratory courses in the chemistry-related fields. Ideas of GSC are discussed in almost all fields of chemistry teaching. Series of strategies for practical work infusing green chemistry have also been proposed. These include a broad spectrum of possibilities: selecting rational contents or experimental topics with environmentally benign raw materials, choosing alternatives procedures, solvents, catalysts, products, and byproducts, selecting optimal synthesis routines using atom economy, popularizing microscale experiments, using virtual or low-cost experiments, utilizing new technologies such as micro- and ultrasonic waves, rationally refining experiment devices, recycling lab materials, and sorting or treating laboratory wastes (Bai et al., 2015; Chen et al., 2013; Wang et al., 2017a, b; Xie et al., 2010a, b). Most papers highlight the green improvement of existing chemistry experiments, especially for organic chemistry experiments. These include the substitution reaction of methane and chlorine with a micro-scale device (Yan et al., 2018), the synthesis of ethyl acetate (Cao et al., 2010), the use of a microscale experiment of determining amino acid (Cai et al., 2013), employment of a series of micro-polymer chemistry experiments (Li et al., 2011), selection of a green fiber catalyst used in organic synthesis (Xie et al., 2016), and the choice of a solvent-free emulsion and foam fractionation, respectively, in the extraction of lycopene from tomato sauce (Zhu et al., 2008; Wang et al., 2010a, b).

Furthermore, green chemistry practices have been suggested to nurture students' awareness of environmental protection and other related areas. For instance, Lin et al. (2020) designed a green electrochemical experiment for college students. They found that it increased students' theoretical knowledge with respect to learning and enhancing green chemistry competencies. Zhou et al. (2018) designed a green chemistry experiment using corncobs as raw materials to synthesize biodiesel, ethanol, and sunscreen to reinforce students' awareness of GSC. Another organic experiment used a safe surfactant to teach and increase students' independent thinking and collaborative abilities (Lu et al., 2017). A model based on "asking-thinking-doing" evaluation was proposed for GSC practical work to enhance students' innovative thinking (Wang et al., 2010a, b). All in all, the topics for GSC experiments and their improved methods are very diverse. The experiments employed are often concerned with fostering students' abilities beyond normal practical skills.

5.3.3. Focus 3: Students' awareness of GSC

Investigations on college students' awareness of GSC are still limited. But the results show that many college students with majors in chemistry or related subjects possess only basic knowledge about green chemistry. They tend to misunderstand the role of green chemistry and its potential role (He et al., 2013; Qiao et al., 2013). This is similar to the results found for secondary education. Zi (2014) implemented a questionnaire to college students. The results indicated that most participants had a sound awareness of environmental protection. However, their associated behaviors were quite feeble due to their weakly-related knowledge of green ideas.

6. Discussion and conclusion

According to a very basic didactic model (Hudson and Meyer, 2011; Sjöström et al., 2020), the four main components of educational practices are the teacher, the student(s), and the content, including their interactions and embeddedness in certain contexts. The relationship can be visualized with the aid of a tetrahedron (Fig. 5).

Context considers classroom-based teaching, educational authorities, society, and culture in the global environment. School and education authorities provide places, standards, and resources for the occurrence of teaching and learning. Society takes over the responsibility for public education and is the original model for schooling (Dewey, 1990). And culture is highlighted here, following the proposed reference subjects of science education by Duit (2007). According to the features and contexts of Chinese GSCE, the framework found in our research is suggested by Fig. 6. This is based on the didactic model given in Fig. 5, the above-mentioned Burmeister et al.'s (2012) model of GSCE, and the identified foci the current study.

GSCE is mainly composed of the GSCE forms found in the classroom plus teaching and learning through practical work, extracurricular activities, and public education in society. The latter comes especially from industry, museums, non-governmental agencies, and social media. These agencies can support GSCE as outreach activities and can influence chemistry teaching as well. International trends in GSCE and the developments of GSC can provide potential contexts and contents for GSCE and influence the attention of educational administration reflecting curriculum standards and textbooks. The local culture, as an invisible assistant can promote the actual implementation of GSCE. All of these together can influence GSCE contents or contexts in connection to another two GSCE core components, namely students and teacher with related implementation and evaluation. Fig. 6 aims at combining all the different present and potential future aspects of GSCE in China that were found and associated by the authors when performing the literature analysis. It provides a suggestion for reflecting relevant factors influencing GSCE in China (maybe even in other countries as well) and

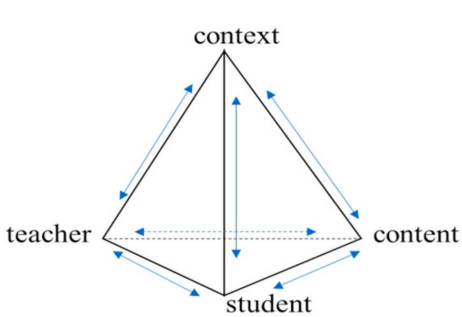

Fig. 5. A didactic model on the interlink of student, teacher, content and context in teaching and learning (adapted from Hudson and Meyer, 2011; Sjöström et al., 2020).

the potential role of relevant actors and fields affected by this development to make them foci of future research and development.

The foci of GSCE in China are broad. The implementation stage of GSCE in Chinese secondary education seems, however, to still be preliminary. It mainly focuses on introducing the first elements of GSC, improving obligatory experiments, and suggesting new teaching strategies. The implementation of GSCE at the secondary level remains mostly at the classroom teaching and practical work level. Aside from this, exercises about GSCE are increasingly emphasized. Connections to other educational stakeholders can only rarely be found. Chinese secondary education seems, however, to be poised on the brink of the next development, including highlighting GSCE in the *high school chemistry curriculum standards (2017 version)* (MOE, 2018). But teaching examples and models, chemistry textbooks based on the local culture, and teacher education about GSCE are all quite limited. Teachers' and students' awareness of green chemistry ideas and the associated behaviors remain weak. This is primarily due to the exam-oriented, textbook-focused teaching found throughout China, even though students' environmental awareness falls in line with their scientific competencies without gender or geographical differences. An international evaluation of students' awareness of GSCE (Ribeiro and Machado, 2013) and the related abilities based on GSCE have not yet been fully utilized or discussed. SSI-related GSCE has initially been discussed, but broad implementation is still lacking. The Chinese cultural and philosophical view of GSCE is rarely discussed in the academic literature. Programs for non-formal and informal education on GSCE as an effective support structure for the formal schooling system is not a major focus in the literature.

Tertiary GSCE in China has been going on for about 20 years. There are plenty of related textbooks which have been published. Green chemistry ideas have slowly infused chemistry education. Chinese green chemistry research has also reached the top of the list in international publications. There are several papers on tertiary GSCE, and teaching strategies and green chemistry experiments have the highest emphasis. Since a broader field of chemistry sub-disciplines exists, there is still a clear lack of consensus whether GSCE should be restricted to a single course or made into a cross-disciplinary endeavor throughout the different fields of teaching tertiary chemistry. Within the general realm of chemistry, there remains a lack of systemic introduction into green chemistry, insufficient teaching practice examples in detail, and a need for new and creative green chemistry experiments for all sub-disciplines. The current study suggests that the main method is still frontally-directed teaching instead of inquiry-based teaching at the university level. There also seems to be only a loose connection between chemistry teaching and chemistry research. This is a not a fully-exploited resource at present. Teaching the use of the latest GSC research outputs at Chinese universities is an approach with a lot of potential (Ma and Zhao, 2018). Due to excellent international research work on GSC research, researchers at Chinese universities should more responsibly disseminate GSC ideas and their research works in GSCE. They should also explore rational and available teaching and learning resources for secondary school teachers by cooperating with schools or building non-formal open laboratories. The development of new and effective pedagogies for GSCE is still necessary, since this is an ongoing challenge for instructors. The core concepts of sustainability are rarely mentioned in many GSCE research works. Newer theories and the *Sustainable Development Goals* (SDGs) are experiencing the same situation. Setting up related websites about GSCE can assist both teachers and students in gaining transferable resources for both secondary and tertiary GSCE (Kennedy and Chapman, 2019). Compared with secondary GSCE, tertiary education is generally more diverse and advanced. It tends to use more modern education technologies and ideas, implement improved experiments geared towards nurturing students' related abilities, and employ examples of various outreach activities. But, the literature also suggests that college students' awareness and understanding of GSC remains low. Among the reasons for this may be the mainstream role of direct teaching, the existing limits in necessary resources, and the

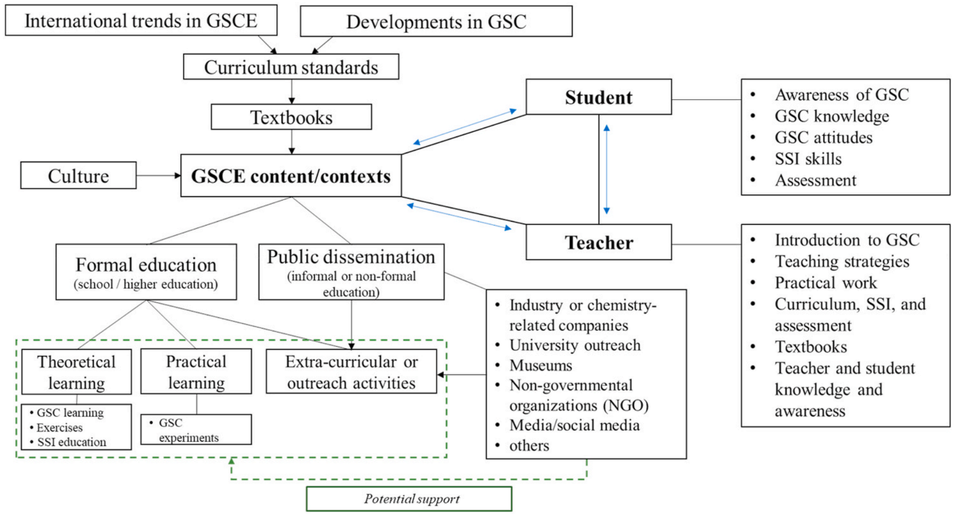

Fig. 6. A suggested framework for reflecting influential factors and potential actors or fields of action to be reflected when it comes to implementing GSCE in China.

current gap between scientific research and GSCE.

Communities of GSCE research in mainland China are not yet visible at the secondary school level. Chemistry education researchers may need more communication about GSCE, not only at the national level, but also internationally. The strengthening of both communication and cooperation between in-service secondary school chemistry teachers and university teachers, other related agencies and authorities remains especially important. The *Green Chemistry Creativity Biannual Competition* for senior secondary students held by the Taiwan education and environmental protection authorities has been successfully launched since 2014 (Green Chemistry Education Website, 2020). It has strongly promoted GSCE. This might be one idea for inspiration, just like the many other related activities in various countries or regions around the world. Many innovative green chemistry experiments are invented each year by Chinese teachers and students. Most of them are introduced in the journal of *Chemistry Education in Taiwan*, but also in other international journals. Related summer camps and workshops for students and teachers have also been supported since 2018 by the Taiwan educational authority. To assess the benefits of international collaboration and communication with western researchers, related research about SSI in Taiwan (Chang and Chiu, 2008; Wang et al., 2017a, b) may be helpful. This could provide mainland China with secondary chemistry education examples which can be used to further strengthen GSCE. Workshops about GSC experiments or online GSCE resources (Kennedy and Chapman, 2019) are another idea which can provide support to teacher educators and secondary school teachers in order to popularize GSCE in secondary education (Kulandaisamy and Karpudewan, 2020).

CRediT authorship contribution statement

Baoyu Li: Conceptualization, Methodology, Software, Visualization, Formal analysis, Writing – original draft, Writing – review & editing. **Ingo Eilks:** Conceptualization, Methodology, Formal analysis, Resources, Writing – review & editing, Supervision, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Paper 2

Education for Sustainability Meets Confucianism in Science Education

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ARTICLE

Education for Sustainability Meets Confucianism in Science Education

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Abstract

Confucianism provides a specific view on the world held by many people living in several Asian societies. It offers views on humans and nature that generally differ from other traditional or Western modern views. The paper presents a systematic analysis of the literature in education with a focus on science education about the connection of Confucianism with education for sustainability. It suggests a framework for how education for sustainability can be operated in the foreground of Confucian societies taking concepts from the international literature into consideration. This critical review provides justification for a stronger reflection about how to include ideas from Confucianism into education for sustainability in the teaching and learning of science. It suggests that Confucian thinking offers a rich and authentic context for science learning in Confucian societies and also provides a chance to reflect on views of humans, nature, and science in science education in other societies, potentially contributing to the development of more balanced and holistic worldviews.

1 Introduction

As technological development brings modern societies to the global community, global development is accompanied by many human made challenges, such as climate change, global pollution problems, gradually decreasing natural resources, or biodiversity loss (United Nations Environment Program [UNEP], 2012). Because humans became the most influential factor to the world, geologists suggested calling our epoch now as the Anthropocene (Caro et al., 2012). The Anthropocene concept suggests that humankind needs to take responsibility for the world; change in behaviors is suggested to reduce negative human impacts on the Earth (Jeong et al., 2021; Ogden et al., 2013). To fend these challenges, the United Nations (UN, 1987) made the concept of sustainable development a regulatory idea of international policy: "Sustainable development is development that meets the needs of the present generation without compromising the ability of future generations to meet their

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own needs" (UN, 1987, para.1). In other words, the current generation is asked to re-think their lifestyles for the sake of the rights and needs of future generations. Sustainability, or sustainable development, emphasizes maintaining sustainable living conditions. Although the concept of sustainability has been under constant debate for many years (Hopwood et al., 2005), most of them refer to a balanced development under ecological, economic, and societal sustainability (Burmeister et al., 2012; UN, 1987).

To further promote sustainable development around the world, the United Nations (UN) coined the term Education for Sustainable Development (ESD) in the Agenda 21. ESD means to educate people to be able to make informed decisions and take responsible action in line with the sustainability ideas of ecological integrity, economic feasibility, and societal justice (United Nations Conference on Environment and Development [UNCED], 1992). ESD proposes a continuously updated education for sustainability to promote current and future generations having abilities to live sustainable lives. ESD suggests learning and acquiring related skills about sustainability in schooling and higher education and also in informal, nonformal, and lifelong learning (UN, 2015; UNCED, 1992; United Nations Educational, Scientific and Cultural Organization [UNESCO], 2005a, 2016). The political vision of ESD, and related concepts with slightly differing visions (Öhman & Östman, 2019), led to an exponential growth of related scientific research articles in the last 30 years in general and in science or chemistry education in particular (e.g., Burmeister et al., 2012; Herranen et al., 2021; Jegstad & Sinnes, 2015; Juntunen & Aksela, 2014).

Education for sustainability (or ESD, sustainability education, etc.) is more than environmental or moral education. It is the fruit of evolution of environmental education and the leading approach for environmental protection now, for its stressing social contribution to deal with major contemporary ecological issues, rather than mainly relying on the study of science for environmental protection (Castellanos & Queiruga-Dios, 2021; McBeath et al., 2014). It concerns the ethical values of individuals concerning individual life, society, economy, and environment in a systems thinking approach (Mahaffy et al., 2018). Its implementation should consider students' and society's ethical and cultural values about local and global sustainability and promote appraisal of the rights and chances of others (e.g., Feng & Newton, 2012; Li et al., 2016b; UNESCO, 2005b).

In school education, science education plays an important role for ESD. Science education is teaching and learning of and about science, including scientific knowledge itself, and the development and utilization of it (Herron, 1969). Scientific theories and knowledge highly relate to and directly reflect the development of industry and technology and their impacts on the natural environment, society, and the economy. Science knowledge is essential for modern citizens' lives, and science is part of the culture in any society, being in Western or Eastern industrialized societies, countries of the Global South, or indigenous living peoples (Zidny et al., 2020). Science education also plays an important role in preparing future scientific literate citizens, scientists, and related experts. Science education is traditionally implemented as one core field of school education in most educational systems, and both teaching science knowledge and teaching about science are highly recommended, such as about the nature of science and its societal ramifications (e.g., Hansson & Yacoubian, 2020; Hofstein et al., 2011; Holbrook & Rannikmae, 2007; Park et al., 2020; Taber, 2017).

Science education for sustainability (or science education in ESD, science education for ESD, etc.) is used here as a term with the understanding of education to promote sustainability knowledge and skills through or in science education. It can be defined in different ways. One way is to see it as the research field where science education meets environmental/sustainability education (e.g., Dillon, 2014; Herranen et al. 2021).

Another related way is to see it as science education driven by a sustainability vision (e.g., Colucci-Gray et al., 2013; Sjöström, 2018; Zidny et al., 2020). The latter is based on a view of science that goes beyond reductionist Western modernization. It is characterized by, e.g., complexity, uncertainty, epistemological reflections, and transdisciplinarity. Such an approach emphasizes "the interplay between facts and values and the way in which we build and make use of new knowledge" (Colucci-Gray et al., 2013, p. 138).

The above-mentioned, negative side effects of Western modern societies' development are particularly also shown in present mainland China caused by its rapid economic growth during the past few decades in connection with its big territory and the world's largest population. Education for sustainability is urgently needed in mainland China. Moreover, mainland Chinese students have drawn lots of attention from international education scholars, due to their frequently excellent science performance in the international science assessments, such as the *Trends in International Mathematics and Science Study* (TIMSS) and the *Programme for International Student Assessment* (PISA) during these years (Cheng & Wan, 2016; Grosseck et al., 2019). However, literature about how ESD is implemented in school science education in mainland China is still limited (Li & Eilks, 2021).

Culture deeply influences not only individuals' ways of living and thinking, but also learning or teachers' teaching approaches. It forms certain patterns of education in a society, due to the differences of history, values, philosophy, beliefs, and behaviors (e.g., Chuang, 2012; Gorry, 2011; Gündüz & Özcan, 2010). Culture is also a direct factor for how people are thinking and knowing about the physical world (e.g., Cobern, 1993; Gao, 1998). This is of importance if a new paradigm of education, like ESD, is to be implemented in general and in science education in particular. Mainland China has one large people of Han with the largest population in the world and 55 ethnic minorities. Han Chinese also take the largest part of Chinese communities in Asia and other parts of the world. They have highly been influenced and maintained by Confucianism, generation by generation (Cheng & Wan, 2016). According to Ogawa (1989), Western modern science, as part of the imported culture from Western civilization, should be taught by concerning local traditional and scientific ways of understanding and observing nature in non-Western countries.

As Chinese scholars look back to Chinese traditional culture, they find that Confucian wisdom about friendly living in nature has potential value to deal with modern ecological problems by leading action towards a sustainable future (Chen, 2019; Chen & Bu, 2019; Cheng, 2013). Confucian ecological ethics, as a cosmological metaphysics, emphasizes that humans and nature are one dynamic, holistic, and organic body, where humans harmoniously and sustainably live together with all the things in nature (Chen & Bu, 2019; Li et al., 2012; Tu, 1998, 2001, Tucker, 1991). Confucianism suggests that humans should love all things in nature and carefully, mildly, and prudently use natural resourses (Chen & Bu, 2019; Li et al., 2012; McBeath et al., 2014). This can be understood as a contribution to sustainability. Confucianism is a moral code with the core Confucian spirit of benevolence, highlighting self-cultivation of moral ethics, which is also related to the intended outcomes of modern ESD (Tu, 2001). Even though China has adopted environmental education and ESD since 1992, Confucian ecological ethics is still not paid enough attention to in ESD in China until now in general and science education in particular (Li & Eilks, 2021; McBeath et al., 2014). Therefore, based on a systematic analysis of the literature, this paper tries to identify the features of and explore a potential model for ESD in science education in the context of Confucianism.

2 Confucianism, Education, and Science

2.1 Confucianism, Neo-Confucianism, and New Confucianism

Confucianism is the dominant ethical and philosophical thought in Chinese communities established by the Chinese philosopher, politician, and educator Confucius (551–479 BC) about 2500 years ago (Fung, 1948; Huang & Asghar, 2018; Li et al., 2016a; Sun et al., 2016). Confucianism is the predominant philosophy that is deeply rooted in every Chinese person (Chiu, 2002). It covers educational, social, ethical, governmental, and economic aspects of all levels of society (Li et al., 2016a; Sun et al., 2016) and provides norms and paradigms of different hierarchies of people's daily lives (Feng & Newton, 2012). It continuously influences life in Chinese societies nowadays and is deeply embedded in Chinese culture (Kwek & Lee, 2010; Li et al., 2016b; Sun et al., 2016), with culture being understood as the mental pattern of feeling, thinking, and acting for a group of people, nationally, regionally, or globally (Hofstede, et al., 2010). In the same culture, people share common customs, beliefs, values, attitudes, and behaviors about certain issues (Guy, 1999). Culture leads individuals to have corresponding behaviors, values, and perceptions advocated and admitted by society (Chuang, 2012; Yorks & Sauquet, 2003). As such, Confucianism profoundly shaped the cultures and histories of many East Asian countries or regions, such as mainland China, Hong Kong, Macao, Taiwan, Korea, Japan, and Vietnam (Li et al., 2016a), including countries containing large minorities of Chinese, for example, Malaysia (Foong & Daniel, 2013) and Singapore (Cheng & Wan, 2016).

Confucius dedicated his life to the teaching for individuals' self-cultivation of virtues. Confucianism aims to build a stable and harmonious society with ethics and morality by the hierarchy of gender, age, and social status-based relationships in the society and family (Chinn, 2002; Huang & Asghar, 2018; Lai, 2008; Schirokauer, 1991). Confucianism stipulates that people should have proper and good behaviors according to the situations and their different hierarchical statuses and roles. People should obey and respect their leaders, in consideration of the kindness and fairness given from the leaders (Chinn, 2002; Feng & Newton, 2012; Lee & Kim, 2019). Similarly, in a family, the older persons foster the young, and the young give them "filial piety" in return (Liu, 2013). In Confucianism, education is underscored as the most important power and tool for guiding individuals' moral practices to sustain a stable and prosperous society. On the other hand, Confucianism emphasizes that education plays a pivotal role in nation building by instructing the people (Guo, 2006). It follows that a teacher is widely respected and is the authority in the teacher-student relationship (Lee & Kim, 2019) but also has full responsibility for students' learning.

Confucius's thoughts about human ethics and morality were recorded in the Chinese ancient book of *the Analects* by his students (Liu, 2013). This book reveals that Confucius highlighted the practice of ethical virtues of benevolence (*ren*) and propriety (*li*) to build order for society. Confucius depicted a certain type of person as "a noble person" (*junzi*), who takes the role of the moral authority and responsibility for bettering society. Confucius advocated an individual to become a *junzi* with moral awareness and autonomy (Brindley, 2011). His teaching thoughts in *the Analects* still influence Chinese pedagogy today. Confucian scholars later further developed the thoughts of Confucius, which gradually formed Neo-Confucianism, especially in the Song (960–1276) and Ming (1368–1643) dynasties.

Neo-Confucianists absorbed significant ideas of Taoism and Buddhism about environmentally friendly practices (Chen & Bu, 2019; Fung, 1948; Wang, 2012), added philosophical views of Confucian ethics and put ethical virtues broadly into cosmology, and subsequently shaped a more rational and dialectical Confucian thought system. Neo-Confucianism mainly focuses on naturalistic cosmology and the ethics of self-cultivation in the anthropocosmic views with ecological concerns. The anthropocosmic Confucianism vision asserts that humans should harmonize with the universe and gain knowledge by self-cultivation (Savelyeva, 2017). Neo-Confucianism also was brought into Japan, Korea, and Vietnam and influenced their cultures and education (Tucker, 1991). Neo-Confucianism of Yulgok from Korea is cosmoanthropic. It means the unity of human and nature is controlled by the universe (Savelyeva, 2017). In Neo-Confucianism, the universe is understood as a vital and dynamic holism where everything interacts with each other and has its own force to change and transform. Humans should rationally use the environment to maintain a fundamental living and harmonize with their natural environment through cosmological concerns and human ethics of self-cultivation (Tucker, 1991).

New Confucianism began in the last century and inherited Neo-Confucianism in mainland China, Hong Kong, and Taiwan, due to the influence of Western civilization. New Confucianists, also called Modern Confucianists, rethought Confucian ideas and infused Western thinking into Chinese traditional thoughts for highlighting the positive role of Chinese traditional culture (Tu, 2001). According to Zagonari (2020), Confucianism has great potential to achieve local and global sustainability. Due to the influence of Western countries with much more developed science and technology to China in the nineteenth century, the last Dynasty of Qing collapsed in the early twentieth century, and the new culture movement (1915–1919) tried to completely adopt Western science for recovering the country and criticized and abandoned Confucianism. It caused Confucianism to become peripheral. Moreover, anti-Confucianism was one theme in the Cultural Revolution (1966–1976) in mainland China (Liu, 2013; Park, 2011). However, the "Reform and Opening Up" policy in mainland China since 1978 brings a new era of Confucianism enlightenment for the international communication of new Confucianists, and it also provides the condition for people to revisit traditional culture treasures (Liu, 2013).

2.2 Confucianism and Education

Education has a high position in Chinese culture. The rapid development of the economy in mainland China in the last 40 years has brought huge progress in the quality of most people's lives. It has also brought high expectations of Chinese parents and society about the quality of education for children. Mainland China with its large population also has a corresponding vast number of school students (Liu et al., 2015). In 2019, the promotion ratios of primary school graduates and lower secondary school graduates reached 99.5% and 95.5%, respectively (Ministry of Education [MOE], 2021).

Growing industrialization and urbanization raised the value of education in people's view from mainland China. During the last few decades, the enormous investment in education was put into schools and higher education, including infrastructure (e.g., improvement of school science laboratories), implementation of reforms (e.g., new school science education standards), and raising human resources (e.g., enhancement of science teacher education) (Liu et al., 2015). Scientific literacy and scientific competence were introduced in the new educational reforms, which tried to blend the knowledge-centered instruction from the past with international trends and the developments of skill-based science education (Li & Eilks, 2021). ESD in school science education becomes highlighted in the current round of science education reform in mainland China (Li & Eilks, 2021), but it is still a field to be developed (Chen et al., 2019).

Confucianism still plays a dominant role in influencing Chinese education (Wan et al., 2018). Although the strict hierarchies of people from the past vastly disappeared in modern Chinese societies, individuals' obedience and respect to authorities or leaders in family and society are still embedded in Chinese moral ethics (Feng & Newton, 2012). Harmonism is considered the highest value of Confucianism to avoid conflicts and reconcile problems. It brings people to actively collaborate with excellent results. Some researchers (Chan, 1999; Feng & Newton, 2012) argue that it might hinder students' development in critical thinking if they are raised to obey their teachers and parents without objection. In fact, interactive discussion and questioning are encouraged in accordance with *the Analects*. It can be achieved as long as the teacher provides the right atmosphere (Tweed & Lehman, 2002). Chinese traditional culture, however, has a strong ability to infuse imported cultures, such as Buddhism. The integration of Confucian and Western education is seen as positively supporting Chinese education reforms in times of globalization and can provide potential ways to deal with certain problems if arising in Chinese education (Yang, 2019).

Confucianism determines the contents and methods of learning as one of the most important activities and highlights ethical knowledge rather than practical or technological knowledge (Hung, 2016). Confucius was considered the model teacher for generations and made East Asian students extremely respectful to teachers as their mentors and role models. Confucius highlighted that all individuals should equally have the chance for education regardless of their backgrounds (*you jiao wu lei*), and teachers' instructions should fit students' abilities and individual needs (*yin cai shi jiao*) (Huang & Asghar, 2018).

Confucianism advocates individuals' efforts to learn by intrinsic and extrinsic motivation with reflection and investigation (Lee, 1996) and teachers' competent capabilities for tirelessly teaching all kinds of students with heuristic instruction. This can be shown in many phrases of Confucian classics. For example,

> [Confucius] said, "I do not open up the truth to one who is not eager to get knowledge, nor help out any one who is not anxious to explain himself. When I have presented one corner of a subject to any one, and he can not from it learn the other three, I do not repeat my lesson." (*bu fen bu qi, bu fei bu fa. Ju yi yu bu yi san yu fan, ze bu fu ye*.) (*the Analects*, 7:8, translated by Legge, 1861a, p.61)

Confucian education suggests that teaching and learning can facilitate each other, and teachers also are considered learners (Hung, 2016; Meyer et al., 2017; Zhao, 2013). In addition, Confucianism advocates that instruction should be implemented step by step at a suitable time, and students are encouraged to learn from each other, including group discussions. It is in line with the effective teaching strategies shown in *Liji:Xue Ji.* They are,

> [t]he rules aimed at […] were the prevention of evil before it was manifested; the timeliness of instruction just when it was required; the suitability of the lessons in adaptation to circumstances; and the good in fluence of example to parties observing one another. (*da xue zhi fa: zhi yu wei fa zhi wei yu, dang qi ke zhi wei, bu ling jie er shi zhi wei xun, xiang guan er shan zhi wei mo*.) (16:3, translated by Legge, 1885, p.86)

Confucian learning is seen as a process of studying, questioning, thinking, and practicing by investigation, reflection, inner motivation, and surrounding influence (Cheng, 2016). Confucian education is moral education for a person advocated to be a noble person (*junzi*) based on ideas of Confucianism and the learning of Confucian classics without the knowledge of formal logic and mathematics and science (Liu, 2013). Confucius, as one versatile teacher, dialogically led to all kinds of students' active and effortful learning based on their abilities and life experiences, guided them to explore answers to their ethical questions, and reflected their teaching and learning for evaluating students' progress and behaviors, under the educational goal of becoming a *junzi*. As formal education with national examination systems was established over time, active learning was replaced by a focus on students' memorization without questioning ethical issues (Guthrie, 2011; Ho, 2018; Hung, 2016; Wu, 2011; Zhao, 2013).

Compared with the acquisition of knowledge, it is more important to fulfill one's self-cultivation as a *junzi* in Confucian education (Chen, 2005). The learning, to *junzi*, should be to "extensively study what is good, accurately inquire about it, carefully reflect on it, clearly discriminate it, and earnestly practice it."(*bo xue zhi, shen wen zhi, shen si zhi, ming bian zhi, shen si zhi*) (*Doctrine of the Mean*, 20, modified from Legge's translation, 1861a, p.227). (Neo-)Confucian education emphasizes dealing with knowledge and action, especially in moral education, justice and self-interest, and the relationship between human beings and nature. Its key ideas are kindness, benevolence, and harmonism. As we will describe more in depth later in the text, the harmony among oneself, others, society, and nature, including other nations and cultures, is the goal of Confucian education (Jin & Dan, 2004). The fundamental Confucian education is to develop an individual's character by self-cultivation and the implementation of Confucian virtues of property and benevolence (Ozoliņš, 2017).

2.3 Confucianism and Science Education

Due to the societal and political interest in "Westernization" or "Modernization" in mainland China since the early 1900s, Western modern science knowledge systematically has taken the place of Chinese traditional knowledge at the school level. It has been widely accepted by educational authorities in China as a base to become an industrialized country (Ding, 2015a; Isozaki & Pan, 2016; Ma, 2009).

This adoption of Western modern science for school science education underwent a series of collisions and reconstruction processes between Western modern science and Chinese culture (Ding, 2015a, 2015b; Kennedy & Lee, 2017; Ma, 2009, 2011). For instance, in the New Culture Movement, one of its two slogans was "science," which was expected to completely substitute Chinese traditional culture. Science was seen as the opposite of Chinese traditional culture (Ding, 2015a; Ma, 2009).

The copying of Western science education still exists with its limitations and problems due to the cultural tradition and societal development in mainland China (Cheng, 2018). Accompanying with the political movement of "reviewing Legalism and criticizing Confucianism" at the last stage of the Cultural Revolution, it reached the climax of criticizing Confucianism since the early 1900s in China. In this movement, Legalism, one of Chinese traditional philosophies, was raised and considered the most influential Chinese philosophy for condemning Confucianism. However, it also brought the booming reprint of Chinese classics including Confucian classics shown as critical books and changed the state of burning Chinese classics at the beginning of the Cultural Revolution. Confucian classics, with its strong vitality, were reopened into Chinese people with their views (Zhou, 2006). Furthermore, it was the end of the cultural revolution that brought reinvigorating of traditional culture in education, Confucian education in particular. Chinese educators suggested gradually integrating imported educational theories into local contexts (Jin & Dan, 2004).

This is in line with Taylor and Cobern (1998), who highlighted that science education in non-Western societies should adapt meaningful science content from Western modern science and absorb it into their own local cultures.

Environmental issues became gradually serious with the rapid development of modern industrial China. They addressed new Confucianists' attention to revisiting traditional Confucian ecological ethics and wisdom. They widely thought that the Confucian idea of the unity of heaven and humans (*tian ren he yi*, for more explanations, see below), could remedy ecological crisis caused by Western science built upon the dualism of humans and nature (Meng, 2001; Tu, 2001; Tucker, 2017). The new Confucianist Weiming Tu (2001) suggested *tian ren he yi* as an ecology turn to modern China, to sustain the harmonious relationship among self, others, community, society, and the universe by individual self-cultivation from inside to outside. *Tian ren he yi* implies that human ethics are analogized and extended into environmental ethics, with hierarchy, for caring all living things, including the respect and appreciation of the natural world in Confucianism. An economic system produced from science and moral ethics of humanism is complementary for a sustainable society (Tu et al., 2003). Meng (2001) stressed that Confucianism is value rationality, rather than science with its instrumental rationality. Only the integration of these two kinds of rationality can bring a peaceful society for modern China. However, during the modernization process of China, the argument of the relationship between humanism and science is still existing, especially at the most recent, hot debate on the benchmark for scientific literary for Chinese citizens in Chinese society in 2016–2017. It was discussed whether traditional Chinese knowledge should be included in that benchmark or not. According to Zhang and Liu (2021)'s analysis of the societal viewpoints of the debate, it implies that locality of science, linking between humanism and science, and understanding of nature of science are urgently needed to enhance science education in China. Some researchers suggest for Chinese science education looking backward to the Chinese traditional culture and philosophy and to discuss science education through the Chinese cultural lens (Cheng, 2018; Ding, 2015b; Isozaki & Pan, 2016; Ma, 2009, 2012). Modern Chinese science education is suggested to nurture students with both Confucian humanistic spirits and scientific knowledge (Bai, 2013). A recent analysis of textbooks from mainland China, however, indicates that Western modern science views are still the dominant lens science is approached in education in mainland China (Chen et al., 2019).

3 Confucianism, Education for Sustainability, and Science Education

3.1 Method of the Literature Review

The following discussion is based on a systematic review of the existing international and local research literature in the field. Three databases were analyzed, namely the Web of Science Core Collection, ERIC, and the China National Knowledge Infrastructure (CNKI). The Web of Science Core Collection was chosen as one of the standard databases for the international research literature; ERIC was chosen because of its broader capture of the field of education and CNKI as one of the most popular Chinese academic databases. CNKI was concerned to also explore publications from the Chinese context that are not captured in international databases because of local reasons or language barriers.

In the Web of Science Core Collection, screening "confucian*" by topic (the asterisk allows a search of both Confucianism and Confucian) gained 8814 hits retrieved on 24

August 2021. They are distributed over many disciplines, mainly Asian studies (2164), philosophy (2146), religion (874), education research (805), area studies (617), history (567), management (403), social sciences interdisciplinary (386), and others, including environmental studies (69) and education scientific disciplines (38). In total, 215,506 hits were found for the topic "sustainability" (531,460 hits of sustainab*). Most of them are about environmental science or green and sustainable technologies. The search terms were chosen for gaining a broad picture as the background of research in the international communities. Combined searching for confucian* and sustainab* by topic in the Web of Science Core Collection produced 108 hits (78 articles, 3 book chapters, and some proceedings papers), retrieved on 24 August 2021. To analyze the relationship of Confucianism and sustainability in the context of the international literature on education, all these papers were read and extracted by hand to exclude unrelated papers without relevant content. Forty-two target papers were identified. Twelve of them are about ecological, moral, or environmental education.

In ERIC, there were 760 hits (peer-reviewed only) by searching the topic "Confucianism OR Confucian" (retrieved on 24 August 2021). Most of them are about cultural influences or differences in education. The combined terms "(confucianism OR confucian) and (sustainability OR sustainable)" by topic produced 12 hits. Seven papers were identified by hand, and three were already found from Web of Science search. Finally, 46 papers were identified on Confucian philosophy views about sustainability based on international databases. Some references from the target papers were also included.

A combined search for "(confucianism OR confucian) and science education" by topic resulted in 51 hits in ERIC (retrieved on 24 August 2021). Some obviously unrelated papers from the title and abstract were excluded, such as health or mathematics education. Others were further read and refined by hand, whether relevant or not. Twenty-two articles were identified, dealing with school or college education from mainland China (9), Hong Kong (1), Taiwan (4), and other East Asian countries or regions (8), such as Korea, Vietnam, and Malaysia. Although Confucian culture in a certain country may have slightly or big different explanations as to the societal, political, and historical changes compared to mainland China, articles from these other countries or regions were nevertheless used carefully as references for respecting general and common ideas. A combined search for "confucian* and science education" in the Web of Science Core Collection also was searched by topic, and resulted in 74 hints, in which 16 papers were refined by hand. Most of them overlapped with the target papers from ERIC, except two papers. Hence, 24 identified papers about science education in the context of Confucianism would be analyzed. To gain more data for this research, the theme of "environmental education" also was concerned. Searching the combined term "(confucianism OR confucian) AND environmental education" in ERIC produced 16 hints. Seven target papers were identified by hand, mainly about theoretical discussions, however, and one of them was gained by the search above as well. Searching the combined term "confucian* AND environmental education" in the Web of Science Core Collection produced 14 hints, and four target papers were identified by hand which were included in the above refining. Therefore, 30 identified papers about science education or environmental education in Confucianism totally were gained, based on the international databases.

To gain a comprehensive picture for this review, a similar search was carried out in CNKI on 30 August 2021. The method of identifying papers was similar to the above-mentioned strategy. Searching "Confucianism" by topic resulted in 58,383 hits of Chinese academic articles in CNKI, mainly about Confucian ideas, culture, and ethics, *the Analects*, modern values, and so on. Searching "sustainability" got 292,205 hits, mostly referring to strategies for sustainable development. Combining these two terms, "Confucianism and sustainability" by topic produced 171 hints, mainly about *tian ren he yi* (the unity of heaven and the humans) (23), Confucian culture or ideas (21), and ecological ethics (21). Seventy-nine papers were refined by hand. Combining search terms "Confucianism and Science education" by topic gained 14 hints. Six papers were identified about the integration of science and humanistic education or any historical analysis of science education in China. Furthermore, eleven hints were obtained by searching combined topics "Confucianism and environmental education," and four target papers were identified by hand. They are about environmental education concerning Confucianism.

All in all, the above-mentioned searching results with representative papers are shown in Table 1. The first round of analysis focused on Confucianism and sustainability in a philosophical view, and the second analysis then tried to map current features of science education and environmental education in Confucian culture and then combining the first round analysis to portray science education for sustainability in a Confucian view. There are huge differences in students' abilities, learning environments, contents, education goals, etc. from pre-primary to tertiary education. The following literature analysis has its focus on secondary education since it is suggested that secondary students have already developed an understanding of science and culture, and at the same time, a lot of basic knowledge and skills for promoting sustainability must be promoted at this level. Nevertheless, research papers concerning other educational levels were also concerned as references for gaining general and common ideas.

Table 1 Research publications about sustainability and science/environmental education in the Confucian culture based on Web of Science, ERIC, and CNKI

Related topics	Databases and the number of hints (refined papers in the parentheses)	Representative papers
Confucianism AND sustainability	Web of Science: 108 (42) ERIC: 12 (7) CNKI:171 (79)	◇ Confucianism and sustainability: Cheng, 2012, 2013; Feng & Newton, 2012; Hsu, 2015; Tu, 1998, 2001; Li et al., 2016b; Mok, 2020; Tucker, 2017; Tucker, 1991; Wu, 2019; Xu et al., 2014; Yu, 2007; Zeng & Liu, 2002; Zhao, 2019; Zhuang, 2015
Confucianism AND science education	Web of Science: 74 (16) ERIC: 51 (22) CNKI:14 (6)	◇ Science education: Foong & Daniel, 2013; Ho, 2018; Huang & Asghar, 2018; Meng, 2004; Liu et al., 2015; Sjöström, 2018; Thomas, 2006
Confucianism AND environmental education	Web of Science: 14 (4) ERIC: 16 (7) CNKI:11 (4)	◇ Environmental education: Chen, 2007; Kim & Roth, 2008; Luan et al., 2020; Yang & Weber, 2019; Zhang et al., 2020

3.2 Confucianism and Sustainability in a Philosophical View

Confucianism suggests ethical standards and values for individuals' attitudes and behaviors in Chinese societies (Chiu, 2002; Kwek & Lee, 2010; Zhang et al., 2020). In more detail, Zhang et al. (2020) presented some characteristics of Confucianism to improve people's eco-friendly awareness, namely behavior-identity matching, self-esteem and reputation, and listening to others (Wang et al., 2017). Individuals' behaviors influence family and social identities and their reputation (Contrada et al., 2001), and they tend to obey the authority and depend on others' opinions for showing their respect to others. It is suggested that core ethical norms and ideas of Confucianism profoundly present environmental friendliness for the modern world.

The core Confucian ethical norms are called five constant virtues (*wu chang*). They include benevolence (*ren*), righteousness (*yi*), propriety (*li*), wisdom (*zhi*), and trustworthiness (*xin*) (Chen, 2015; Kwek & Lee, 2010; Meyer et al., 2017; Sun et al., 2016).

- Benevolence is considered the most essential concept in Confucianism (Kwek & Lee, 2010; Meyer et al., 2017). It means "to love others" and contains generousness, respect, kindness, caring, sympathy, empathy, and tolerance to others (Low, 2011; Sun et al., 2016). Its root or starting point is "filial piety," which means being filial or respectful to one's parents (Tan & Tan, 2014). The Confucianist Mencius (372–289 BC) stressed that "[a noble person] is affectionate to his parents, and lovingly disposed to people generally. He is lovingly disposed to people generally, and kind to creatures." (*qin qin er ren min, ren min er ai wu*) (*Works of Mencius*, 13: 45, translated by Legge, 1861b, p.352). Benevolence is also shown in the remark: "[Confucius] angled, –but did not use a net. He shot, – but not at birds perching" (*zi diao er bu gang, yi bu she su*) (*the Analects*, 7:27, translated by Legge, 1861a, p.67), including Confucian frugality virtue, connecting modern "green consumption." Benevolence is the intrinsic power for the suitable and enduring implementation of external propriety (Christensen, 2017). This is related to a core value of sustainability as benevolence and love to all creatures. This value advocates individuals to treat all things kindheartedly to nurture environmentally friendly awareness (Li et al., 2012; Zhang et al., 2020).
- Righteousness is the standard for appropriate behavior (Yu, 2007). It pursues a just distribution of rights and benefits, duties, and responsibilities to achieve a harmonious society (Cheng, 2012). Confucius depicted that "[t]he mind of the [noble person] is conversant with righteousness; the mind of the mean man is conversant with gain" (*jun zi yu yu yi, xiao ren yu yu li*) (*the Analects*, 4:16, translated by Legge, 1861a, p.34). Righteousness is the right attitude nurtured by benevolence, and righteous actions are the imperative presentation of fulfilling benevolence, rather than by the short-term benefits (Cheng, 2012). In terms of sustainability, righteousness can be related, e.g., to respect norms for resources protection and societal sustainability.
- Propriety guides humans to have proper actions or interactions with others and the environment for avoiding conflicts based on social rituals and manners (Meyer et al., 2017; Wu, 2019). It is "the ritualized body language of benevolence" (Bockover, 2012, p. 180), and its most significant mission is to attain harmony (Cheng, 2012). In terms of sustainability, propriety can be related, e.g., to put individual interest last to come up with sustainability challenges.
- Wisdom is a quality in an individual who has intelligence knowledge for self-cultivation to deal with certain problems and then take proper moral actions to gain good

results by following social rituals (Cheng, 2012; Kwek & Lee, 2010), and it is the foundation for the implementation of morality (Cheng, 2012). People with wisdom can learn how to live harmoniously in order to understand the world with benevolence. For instance, Confucius said, "The wise find pleasure in water; the [benevolent] find pleasure in hills." (*zhi zhe yue shui, ren zhe yue shan*) (*the Analects*, 4:16, translated by Legge, 1861a, p. 56). It also shows that Confucianism innately enjoys the natural world. In terms of sustainability, wisdom can be related, e.g., to knowledge about sustainability issues, the underlying values, and potential consequences.
- Trustworthiness is the trust of others and knowledge based on one's understanding and observation of the world. Trustworthiness is the inevitable part to sustain a harmonious world, for it promotes the common good virtues or spirits in society through effective and dependable communication (Cheng, 2012). In terms of sustainability, trustworthiness can be related, e.g., to acknowledge that sustainability is a challenge that societies can only achieve together.

The Confucian five virtues are similar to the German philosopher Herbart's five moral ideas, namely, benevolence, right, equity, perfection, and internal freedom (Meyer et al., 2017). According to Sjöström (2018), Confucian education also has similarities with the Central and Northern European educational tradition called *Bildung*. Many parallels can be found to connect Confucian education with *Bildung*, a German word that, among other things, understands education as the formation of a person to become able to live a self-determined and solitary life in society (e.g., Hofstein et al., 2011; Horlacher, 2016; Sjöström et al., 2017; Sjöström & Eilks, 2020).

Bildung in the Central and Northern European tradition is a word for both the process of formation of a person and the final aim to be achieved. A similar concept can be found in Confucianism. The concept of sincerity (*cheng*) is understood as the starting and the return point of one's ethical self-cultivation and the highest virtue of Confucianism (Yu, 2007). Sincerity is not only a process but also a state (Wu, 2019; Yu, 2007). Sincerity contains one's self-actualization and the completion of all things; it can support humans to gain the self-understanding of environmental concerns in the ideal and real life (Wu, 2019). In other words, Confucianism suggests that people follow environmentally friendly ethics and carry out relevant activities or behaviors to accomplish their autonomous self-formation (Christensen, 2017; Li et al., 2016b). Sincerity also encompasses the sustainability idea of inter-generational justice. The Neo-Confucianist, Zhang Zai, said his self-aspiration is "to ordain conscience for Heaven and Earth, to build the Way for people, to continue lost teachings for the past sages, and to bring about peace for all future generations" (*wei tian di li xin, wei sheng min li dao, wei qu sheng ji jue xue, wei wan shi kai tai ping*) (Zhu & Lv, 1998, p. 68).

Finally, the light should be shed on the Confucian concept of harmonism (*he*). A Western modern science view suggests looking at physical things separated from each other. Humans consider other things in nature as objects (Pak & Kim, 2016). The Western modern science view can be considered anthropocentric. In contrast, Confucianism highlights the idea of the unity of heaven and humans (*tian ren he yi*), which is anthropocosmic (Christensen, 2017; Tu, 1998, 2001). It suggests that humans and nature together form a holistic and organic body (Li, 2018; Mok, 2020; Tucker, 1991).

In the Chinese traditional culture, the principal idea of *zi ran* (translated as "nature") is *tian ren he yi* (translated as "nature and humans form one body" or "the unity of heaven and humans") which means "Nature and humans have the same origin and belong to the same unity; Nature and humans follow the same law; and, Nature and humans are interconnected" (Ma, 2012, p. 13). *Tian ren he yi* sees nature and humans as an integrated whole with a holistic thought and indicates that human activities can lead to the change of nature, and everything that exists should be in harmony with each other (Chen & Bu, 2019; Ma, 2012). This idea is highly matching ideas of sustainability and holistic thinking and as such related to recent suggestions better recognize systems thinking approaches when it comes to science education for sustainability (Mahaffy et al., 2018).

In Confucian cosmology, heaven and earth are two core Confucian trigrams, as the universe, and the third one is human (Fung, 1948). Humans, as spiritual beings, have capacity of internal echoing among themselves and between all things in the nature to reach *tian ren he yi* (Tu, 1998). *Tian ren he yi* also shows the appreciation of the natural environment, in line with the following description of the natural world from Confucian classics *Doctrine of the Mean*:

> The [H]eaven now before us is only this bright shining spot; but viewed in its inexhaustible extent, the sun, moon, stars, and constellations of the zodiac, are suspended in it, and all things are overspread by it, The earth before us is but a handful of soil; but when regarded in its breadth and thickness, it sustains mountains like the [Hua] and the [Yue], without feeling their weight, and contains the rivers and seas, without their leaking away. The mountain now before us appears only a stone; but when contemplated in all the vastness of its size, we see how grass and trees are produced on it, and birds and beasts dwell on it, and precious things with men treasure up are found on it, The water now before us appears but ladleful; yet extending our view to its unfathomable depths, the largest tortoises, iguanas, iguanodons, dragons, fishes, and turtles, are produced in them, articles of value and sources of wealth abound in them. (*Jin fu tian, si zhao zhao zhi duo, ji qi wu qiong ye, ri yue xing chen xi yan, wan wu fu yan. Jin fu di, yi cuo tu zhi duo, qi ji guang hou, zai hua yue er bu zhong, zhen he hai er bu xie, wan wu zai yan. Jin fu shan, yi juan shi zhi duo, qi ji guang hou, cao mu sheng zhi, qin shou ju zhi, bao zang xing yan. Jin fu shui, yi piao zhi duo, ji qi bu ce, yuan tuo jiao long yu bie sheng yan, cai huo zhi yan*) (*Doctrine of the Mean*, 26, modified from Legge's translation, 1861a, p.284-285)

This holistic eco-ethical view also is represented in the idea of benevolently utilizing natural resources depending on time, guided by the patterns of the natural world (*yi shi jin fa*), e.g., to avoid excess fishing, hunting, and logging, related to sustainable development. It can lead to a sustainable society, for its ecological, economic, and political aspects (Chen & Bu, 2019; McBeath et al., 2014).

Furthermore, *tian ren he yi* also is explained by Neo-Confucianist Zhang Zai in his *Western Inscription*:

> [Heaven] is called the father and [Earth] the mother. We, these tiny beings, are commingled in the midst of them. I, therefore, am the substance that lies within the confines of Heaven and Earth, and my nature is that of the (two) Commanders, Heaven and Earth. (All) people are my blood brothers, and (all) creatures are my companions. (*qian cheng fu, kun cheng mu, yu zi mao yan, nai hun ran zhong chu. gu tian di zhi sai, wu qi ti. tian di zhi shuai, wu qi xing. min, wu tong bao; wu, wu yu ye.*) (Fung, 1948, p. 493)

Based on such an understanding, people should respect the value of nature and learn from nature for humans' ethics and morality (Christensen, 2017; Li et al., 2012; Mok, 2020). According to Confucian filial piety, individuals not only should respect their parents (and other elders), but also need to respect all the things in nature (Tucker, 2017). As shown above, "harmony between nature and humans" (*tian ren he xie*) becomes the core thought of Confucianism about ecology (natural environment) (Li et al., 2012; Li et al., 2016b), as the modern explanation of "unity of heaven and humans" influenced by western civilization highlighting the relationship to form logic thinking based on the dualism of humans and nature (Liu, 2000). It encourages humans to be friendly with all the creatures and cherish life; to know, respect, and love the law of nature; and sustainably to use natural resources or nature (Li et al., 2012; Li et al., 2016b; Zeng & Liu, 2002).

The word "harmonism" (*he*) in Chinese means "moderate, coordinated, and reconciled" (Li et al., 2016b, p. 683). The idea of Chinese harmonism (*he*) is more complicated and sophisticated than the Western idea of harmony (Wang, 2012). For example, in terms of individual self-cultivation, the idea of *he* in Chinese is that an individual has a peaceful mind and heart with benevolence. Harmony between body and mind can be achieved by satisfying the unity of righteousness and profits and improving the spirit world rather than irrationally chasing materials. It is an important starting point for dealing with the external relationship (Zhan, 2005). In terms of human relationship, *he* in Chinese is meant not only to be respectful and friendly to others, but also not to agree to the wrong ideas of his superiors, as Confucius said in *the Analects*, "[t]he superior man is affable, but not adulatory; the mean is adulatory, but not affable" (*junzi he er bu tong, xiaoren tong er bu he*) (*the Analects*, 13:23, translated by Legge, 1861a, p.137). In Chinese, *he* is meant to be harmony or in harmony, while *tong* is just the opposite; the former is an epistemological way of creative knowing, trying to absorb various elements from different things to create something new and valuable, whereas the latter cannot do so (Wang, 2012). "[Confucian harmonism] is a creative process, amid which things are balanced with one another, but amid which something new also emerges" (Wang, 2012, p. 189). "Harmony without uniformity (*he er bu tong*)" is an important idea for facing conflicts or differences in Confucianism, and it is the most effective means to overcome them (Feng, 2010). In terms of the unity of heaven and humans, the idea of *he* in Chinese is more relevant to sustainability. In the Chinese ancient book *Guoyu*, Shi Bo thought that "Mixing one factor with others means harmonism" (*Yi ta ping ta wei he*) (*Guoyu:zhengyu*, 16:5, Zuo et al., 2015, p. 347), and he further pointed out that "Harmonism will create new things, but sameness will not." (*he shi sheng wu, tong ze bu ji*) (*Guoyu:zhengyu*, 16:5, Zuo et al., 2015, p. 347). This indicates that only by integrating different things or factors, new things can be created and developed—a philosophical insight into the nature of matters indeed (Wang, in press). The concept of Chinese harmonism is one of the most important Confucian ideas in the traditional culture, and it is very relevant to science education for sustainability. So, it would be of great importance to be included as one of the significant features of Confucianism (Ding & Su, 2021; Ding & Wang, 2017).

As *Bildung* in German, the Chinese character *he* can be combined with other characters to form many, many terms (see Table 2). All these terms consist of two Chinese characters, with *he* coming first. There are also many two-Chinese-character terms with *he* coming second, and there are much more four-Chinese-character idioms, such as *he er bu tong* (translated as "seeking harmonism, not the sameness" or "harmony without uniformity"). So, these examples indicate that Chinese harmonism is ingrained in the Chinese people's mind and heart through Mandarin. Although there was radicalistic anti-Confucianism during periods of times in modern Chinese history, especially in the New Cultural Movement and in the Cultural Revolution, Confucianism could not be wiped out completely in the mind of the Chinese society.

Confucian harmonism among people and between people and nature can support to live healthier and more beneficial lives in the West and the East in the current globalization era.

Table 2 Popularly used binary terms of Chinese characters consisting of one Chinese character *he* (harmonism) in modern Chinese language

No	Chinese characters	ping yin	English	No	Chinese characters	ping yin	English
1	和平	he ping	Peace	19	和睦	he mu	(Of relationship) friendly
2	和会	he hui	Peace conference	20	和戎	he rong	Peaceful dealings with minorities
3	和议	he yi	Peace negotiation	21	和乐	he le	Happy and harmonious
4	和约	he yue	Peace treaty	22	和美	he mei	Harmonious and beautiful
5	和谐	he xie	Harmonious (relationship)	23	和答	he da	In response to the other in poems
6	和婉	he wan	Mild in tone	24	和番	he fan	Make peace with other countries
7	和合	he he	In one mind with others	25	和气	he qi	Friendly feelings
8	和心	he xin	Peaceful mind	26	和善	he shan	Genial
9	和洽	he qia	In harmony	27	和泰	he tai	Mild and peaceful
10	和蔼	he ai	Affable	28	和声	he sheng	Harmony
11	和谦	he qian	Modest	29	和弦	he xian	Chord
12	和雅	he ya	Gentle and respected	30	和顺	he shun	(Of character of a person) gentle
13	和畅	he chang	(Of a wind) pleasant or gentle	31	和棋	he qi	A draw in chess or other board games
14	和风	he feng	Soft wind	32	和尚	he shang	A monk
15	和雨	he yu	Small rain	33	和味	he wei	Delectable food
16	和玉	he yu	Precious jade, rare treasure	34	和局	he ju	A draw in a game, a tie in a competition
17	和解	he jie	Become reconciled or settled	35	和诗	he shi	A poem that leads to responses in poems by others
18	和好	he hao	Become reconciled	36	和曲	he qu	In chorus in a song

It is an effective way to deal with cultural differences but also limited natural resources (Wang, 2012). It can also facilitate the implementation of sustainability in Chinese science education, to know the western cultures or values and Chinese cultures about sustainability and grasp the rational contents and ideas. Integrating the local contexts and traditional ethics about ecology can gain many advantages for sustainability (Li et al., 2012). Harmonism in Confucianism endorses the unity of all the creatures with diversities, thrivingly and peacefully living together (Zhu, 2010). Such an understanding is in line with modern concepts of sustainability that re-interpret the balancing of ecological, economic, and societal sustainability in a means that:

> The concept of balancing has failed as it always leads to imbalances. In case of doubt, social as well as ecological needs were pushed aside in favour of a growing economy […]. With the knowledge about the planetary boundaries we have to state that the physical boundaries of the natural resources are not negotiable boundaries. In a nutshell: When the biophysical boundaries are absolute we cannot build a relativistic model on them. […] we must re-conceptualize sustainability where the economy serves the social needs of people today and tomorrow and eliminates poverty and hunger. But, it can only act within the planetary boundaries. (Niebert, 2018, p.62)

In Confucianism, humans and nature are in the same ethical system, and the concept of unity of heaven and humans (*tian ren he yi*) is raised, and individuals' practicing ethical morality in the family and the society is highlighted. In Neo-Confucianism, the concept of unity of heaven and humans is further explained, and ethics are essentially practiced among humans and between humans and all the things or beings in the cosmos (Cui, 2012; Hsu, 2015). New Confucianists emphasize individuals' self-cultivation and the pursuit of the way of heaven or nature to achieve harmony between individuals and communities and between humans and nature (Hsu, 2015; Tu, 2001). Above all, Confucian unity of heaven and humans can be understood as the driver for ecological benignity and human ethics (Li, 2018). Confucian ecology stresses ethical conscience. So it can probably provide another way for achieving sustainable development (Hsu, 2015). A potential organizer of (Neo-) Confucian philosophical views about sustainability is provided in Fig. 1 according to Cheng (2012). Sincerity is the initial stage, and benevolence is the core spirit of harmonism. Vital force (*qi*) is the basic element of all the things of the cosmos and bonds them

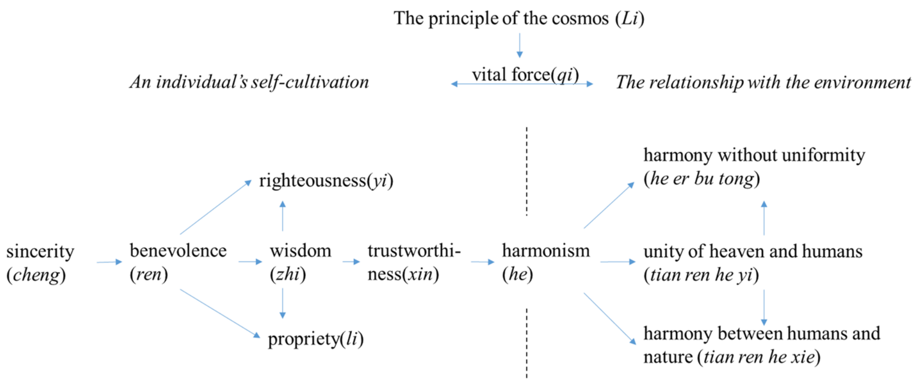

Fig. 1 A framework of philosophical views on sustainability in (Neo-)Confucianism (adapted from Cheng, 2012)

as an entity (Chung, 2012; Mok, 2020; Paton, 2021; Tucker, 2017; Xu et al., 2014). It is very similar to the ideas of matter from Western philosophy, whereas *qi* has accessibility to all things and the intrinsic motility with frequently moving and changing. *Qi* can be considered the unity of matter and energy (Needham, 2004; Zhang, 2002). The left part is the concepts for individuals' self-cultivation which are basic to sustainable development, and the right is the harmony with the environment including living and non-living things. The principle *Li* controls the operation of the universe (Chung, 2012; Mok, 2020; Tucker, 2017).

3.3 Confucianism and Sustainability in Science Education

Huang and Asghar (2018) found that there are cultural restraints and supports as secondary science teachers in Taiwan carried out inquiry-based and student-centered teaching. The equality and equity in Confucian education match with Western modern education, and student-centered instruction is similar to the Confucian education principle of satisfying students' abilities and needs. The science teachers considered Confucian virtues and ethics as an important goal of education for a harmonious and stable society. Teachers should enrich content knowledge and be role models for students. However, Confucian self-discipline and respect for authorities might impede nurturing students' autonomy, critical thinking, inquiry, and creative ability.

Sjöström (2018) suggested that Confucianism has some similarities with Western *Bildung* about ecological friendly views. Neo-Confucian and *Bildung*-oriented science education, or eco-reflexive science education (Sjöström et al., 2016), concerns the awareness of uncertainties, the recognition of benefits and risks of science and technology, and ethical and social factors based on contemporary views of nature of science. Socio-scientific issues (SSI), which are authentic, relevant, present, and controversial, are suggested for improving students' scientific literacy in teaching science (e.g., Bencze et al., 2020; Marks & Eilks, 2009). This teaching approach can develop students' higher-order thinking skills to form rational decisions for involving societal debates and future decisions about related SSIs in becoming responsible citizens (Hofstein et al., 2011; Holbrook & Rannikmae, 2007; Sadler, 2009). Foong and Daniel (2013) implemented two socio-scientific issues in Chinese science classroom and found that this kind of instruction can promote student-oriented learning and relieve the Confucian teacher-centered influence with students' progression in argumentation skills.

Feng and Netwon (2012) implemented a Master's course about sustainability education which is designed based on the harmony principle in Confucianism. They found that the principle of harmony in Confucianism can facilitate the implementation of sustainability education by addressing sustainability issues with respect to others and their different interests. It can help actively collaborative and collective actions. Cheng (2013) suggests that Confucian virtues have potential value for meeting the modern global and local needs of sustainable development. Zhang et al. (2020) mentioned that Confucian values greatly influence Chinese environmental values, attitudes, and behavior. Increasing Chinese recognition of and adherence to Confucian values can positively promote science education (Huang, 2015) and environmentally benign behaviors (Zhang et al., 2020). Modern science education is not only to nurture students with scientific knowledge and motivate their learning, but also to prepare them to be active and responsible citizens (Hansson & Yacoubian, 2020), with a goal of "science education for all and social transformation," expressed as "scientific literacy" on three visions. Vision I focuses on scientific and technical knowledge and concepts in the epistemological view, Vision II is the contextual or application aspect of scientific knowledge connecting students' daily lives (Roberts, 2007), and Vision III suggests multiple cultural perspectives on scientific worldviews for science education for sustainability (Murray, 2015), such as critical-reflexive *Bildung* (Sjöström & Eilks, 2018). As mentioned above, the rapid development of science, technology, and society leads to the modernization of China during the last few decades, but it also faces serious environmental issues. The Confucian idea of harmony between nature and humans, as a sustainability value, might facilitate modern science education for sustainability, in the light of Vision III of scientific literacy in China.

Meng (2004) advocated merging humanist education with science education by effectively integrating Eastern and Western cultures. Chinese educators should concern both Western modern and traditional views of the natural world. It is suggested to revisit Chinese traditional culture about the relationship between nature and humans, to implement a local version of sustainability education and for developing students' environmental awareness (Chen & Bu, 2019; Li, 2020; Savelyeva, 2017). Chen (2007) proposed to increase the recognition of green civilization, provoke treating beings with benevolence, and develop appropriate consumption behaviors, to reach Confucian *tian ren he yi*. Liu and Constable (2010) underpinned connecting the values and knowledge of Chinese culture with global principles for enhancing education for sustainability. Confucian virtues such as benevolence, commitment to harmony, and filial piety are suggested to have positive implications for environmental education (Nuyen, 2008).

Some programs about sustainability education based on Confucian values have already been carried out. For instance, an ecological education program was implemented for highlighting harmony between nature and humans (Kim & Lim, 2007). Kim and Roth (2008) proposed to combine Confucian values of sincerity (*cheng*), propriety (*li*), and righteousness (*yi*) about ecological ethics into Korean environmental education to confront the gap between students' knowing and acting about environmental issues. In short, ethical views are indispensable for promoting scientific literacy in science education for building a sustainable and responsible society (Zeidler et al., 2005). Moreover, sustainability education needs collective efforts, and Confucian collectivism can actively promote the implementation of sustainability education by combining the fostering of responsible and capable individuals and collective learning with global perspectives (Liu & Constable, 2010). Similarly, the (Neo-)Confucian ideas of the unity of knowing and acting (*zhi xing he yi*) and reflection also can make sure to achieve participatory skill competency of sustainability education (Chen, 2019). The relationship between Confucian education and science education for sustainability is mapped in Fig. 2.

Confucianism has advantages and disadvantages for science education for sustainability, and both have some common parts which perform the moral function as suggested in Fig. 2. The core function of Confucian education is moral education in the sense that it makes human beings human. It is generally in line with different concepts of education for sustainability, although different interpretations of sustainability-oriented education exist (Öhman & Östman, 2019). Individual self-cultivation for a noble person and the idea of harmony between nature and humans in (Neo-)Confucianism match with the social, ecological, and economic aspects of education for sustainability. Science education in Confucian culture should highlight moral education based on Confucian values. According to McBeath et al. (2014) and Li and Eilks (2021), Chinese science education research with a focus on sustainability is still at its initial stage. Main foci are introducing teaching strategies and different approaches to practical work. Most of students' and teachers' pro-environmental awareness and behaviors are quite weak at secondary schools.

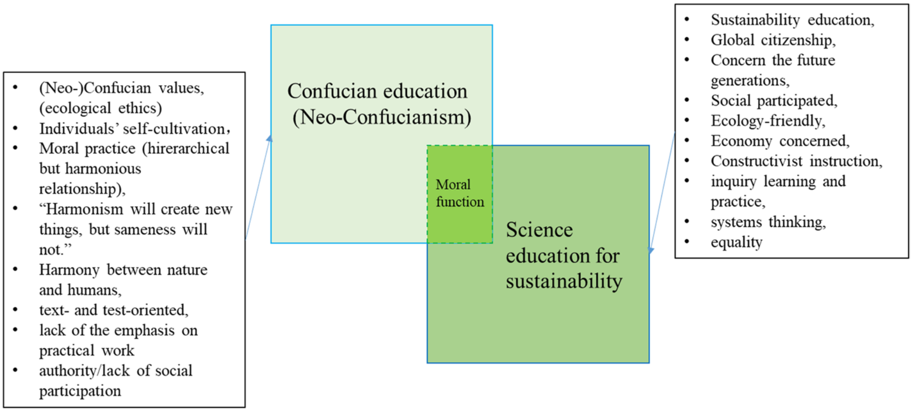

Fig. 2 The relationship between Confucian education and science education for sustainability including significant features

Instruction focusing on socio-scientific issues in science education is just starting. Teachers lack appropriate teaching resources and external support for promoting science education for sustainability, especially in the context of the current national secondary science education standards for use. The persisting emphasis on theoretical knowledge learning is also influenced by the textbooks and the neglect of scientific practices and creativity in modern Chinese science education (Gao, 1998; Huang et al., 2016; Thomas, 2006). Further reasons suggested in the literature are the dominance of teacher-centered instruction (Yeung, 2015), rote learning by just memorizing scientific knowledge, and the strong role and nature of the exams (Chan, 1999) with the paper-and-pencil standard for assessment (Yin & Buck, 2015) that do not match with modern concepts of science education for sustainability. In contemporary educational theory, knowledge is suggested to be constructed by learners' thinking processes and can be constructed by exchange and argumentation (Tweed & Lehman, 2002). This new theory seems to be familiar to many Chinese science educators and teachers alike, but it is very difficult to be thoroughly implemented in the classrooms.

Critical thinking is highlighted in contemporary science education, and one of the core spirits of the nature of science is skepticism (Aikenhead & Ogawa, 2007). Science education for sustainability can lead to student-centered learning and increase students' interest for their more participation by addressing SSIs (McBeath et al., 2014). SSIs provide contexts for students raising questions, and in combination with Confucian education, there is potential for nurturing critical thinking abilities, since questioning is one process of Confucian learning (Hung, 2016; Tweed & Lehman, 2002). Education for sustainability is value-driven and emphasizes environmental ethics (UN, 2015), similar to the behavioral reform of Confucian education including Confucian ecological ethics (Tweed & Lehman, 2002). Confucian collective values could support students' participation in group discussions for contributing their efforts to the collective and developing their thinking skills. Science education for sustainability can promote students' discussion on SSIs so that it will enhance student-centered learning, foster independent thinking and argumentation, and assist in nurturing a Confucian noble person in modern technological society. According to Thomas (2006), science teachers mainly highlight examination and knowledge rather than students' metacognition development in Asian regions in the case of Hong Kong. Students lack self-regulation and accept the authoritative and parental figure of the teacher, due to the filial piety of Confucianism. Compared to international schools, Chinese teachers are stricter with their students in terms of higher expectations of academic results but lack emotional support to their students (Huang & Asghar, 2018; Thomas, 2006). As efforts are seen as the most important requirement for one's achievement in Confucianism rather than intrinsic abilities in Western culture (Lee, 1996), Chinese teachers concern more with the efforts put by students and ignore students' different learning abilities and needs (Lau & Lam, 2017).

However, the authority of teachers in the classroom can assist the implementation of new teaching methods for students' smooth acceptance of it and respect to their teachers in Confucianism (Yin & Buck, 2015). Yin and Buck (2015) noted that formative assessment helped Chinese science education to shift into learner-centered, constructivist teaching. As it is concerned more with students' learning process, it could get rid of relying on "questions sea tactics" of teaching and learning, which means doing plenty of written exercises for better test results. Writing tasks of formative assessment can effectively encourage students to elaborate their viewpoints on certain issues and suit Chinese classrooms. The leading summative assessment, big class sizes, and the limited class time might impede the implementation of formative assessment and need supports from educational authorities and schools. Luan et al. (2020) found that although scientific teaching approaches in environmental education can improve secondary school students' environmental awareness and holistic thinking abilities, the authorities' supports from schools or the society about environmentally friendly ideas or policies can further promote students' decision-making abilities and pro-environmental behaviors for their respect for the authority in Confucian culture. It is in accordance with Fu et al. (2017), who suggest that it is underscored how university environmental policies nurture students' environmental-friendly behaviors as Chinese social and cultural aspects, such as dignity and collectivism, highly influence one's behaviors (Yang & Weber, 2019). Due to cultural factors, systems thinking instructional approaches, including attitudes, knowledge, emotion, and so on, should be implemented for promoting students' sustainability behaviors (Huang & Yore, 2005).

3.4 A Model for the Implementation of ESD in Science Education for Confucian Culture

As Chinese science education today mostly follows the Anglo-American curriculum tradition, a general teaching model is not defined, and the development of its science teaching model is still at the beginning in mainland China. Even though science education research was launched in China in the 1980s, it mainly focuses on the local reconstruction of educational theories from other countries, e.g., inquiry learning and student-centered pedagogies. It is suggested to add research on the theory of science teaching based on theories, goals, procedures, strategies, and assessments for the Chinese educational context (Ma & Zhao, 2018).

As mentioned above, Chinese Confucian education should not be understood as the opposite of Western education (Huang, 2015; Zhao, 2019). Meyer et al. (2017) analyzed the German Didaktik tradition and Confucian philosophy of education as the core of Chinese school education from perspective. They explored Confucian education with the main goals of "humanism, harmony, and hierarchy with discipline" (Starr, 2012, p. 8), in relation to the German Didaktik by Wolfgang Klafki's conception of "self-determination, cooperation, and solidarity" as main goals. They found strong parallels and possibilities of associating these two kinds of schooling visions. Similarly, Sjöström (2018) pointed out resemblances for learning between Confucianism and *Bildung* from Western culture for sustainability education.

In the "(*Bildung*-centered) Didaktik analysis" model for lesson planning by Klafki (2000; originally published in German in 1958), key questions are provided to identify content and approaches for learning (see Table 3). These questions are suggested to identify the suitable topics also for ESD in respect of cultural differences and traditions. The model underscores content-related aspects for all the levels of teaching and learning. It can effectively support teachers to identify and transform meaningful knowledge to their students for ESD in the foreground of any given culture (Arnold & Koch-Priewe, 2011).

The "(*Bildung*-centered) Didaktik analysis" model can be considered a reference model for formulating science education for sustainability, related to Confucian culture in mainland China. Based on this approach, a framework in the means of a Didaktik model (e.g., Sjöström et al., 2020) for implementation of science education for sustainability connecting with Confucianism in mainland China is sketched in Fig. 3. It contains the determination of aims and goals, the selection of topics and contents, the design of teaching materials, media and assessment, teaching and learning methods, implementation, and evaluation. It also includes the context of the entire implementation, which are individual, school, and societal dimensions as well as educational goals. In the globalization era, different cultures harmonious living with diversities (*he er bu tong*) is also concerned. The model is supported by theories of science education for sustainability, Confucian values for sustainability education, and pedagogical and psychological theories including adjusted Confucian education for suiting the features of science learning. Additionally, students' preconditions and existing knowledge influence the implementation. Individuals' behavior and conceptions will interact with their communities and bring change to society.

Western modern science produces scientific knowledge and supports the development of technologies based on Western views of nature and humans and Western modern scientific way of thinking. Thus, science education in non-Western modern societies should be compared to them as regards the traditional cultural views on nature and their way of thinking and should be contextualized by students' traditional local culture (Ogawa, 1986). The views of nature and humans in Confucian culture and sustainability in science education are concentrated and shown in Fig. 3 as well. Modern Chinese students nurtured with scientific knowledge or tools for sustainability, such as systems thinking and life cycle assessment, can effectively deal with humans and nature with sincerity (*cheng*) and Confucian virtues to reach *tian ren he yi* of (Neo-)Confucianism by the integration of knowledge and

Table 3 Key questions of Klafki's (2000) Didaktik analysis

(1) What wider or general sense or reality does this content exemplify and open up to the learner? What basic phenomenon or fundamental principle, what law, criterion, problem, method, technique, or attitude can be grasped by dealing with this content as an "example"?
(2) What significance does the content in question, or the experience, knowledge, ability, or skill to be acquired through this topic already possess in the minds of the children in my class? What significance should it have from a pedagogical point of view?
(3) What constitutes the topic's significance for the children's future?
(4) How is the content structured (which has been placed in a specifically pedagogical perspective by Questions 1, 2, and 3)?
(5) What are the special cases, phenomena, situations, experiments, persons, elements of aesthetic experience, and so forth, in terms of which the structure of the content in question can become interesting, stimulating, approachable, conceivable, or vivid for children of the stage of development of this class?

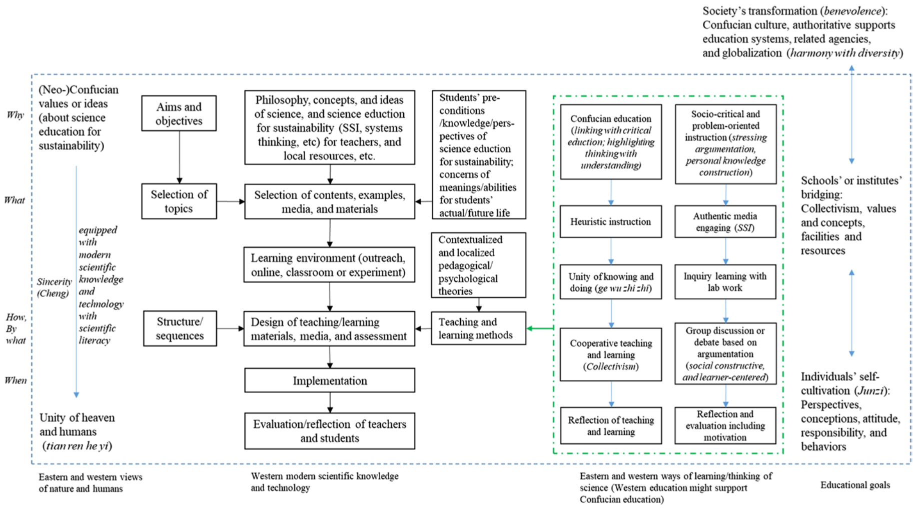

Fig. 3 A framework for the implementation of science education for sustainability connecting Confucianism (based on mainly Du et al. (2013), Heimann et al. (1969), Marks and Eilks (2009), Ogawa (1986), Sjöström et al. (2020), and Zhao (2013))

behaviors. Zhao (2013) drew back to *the Analects* and found the following themes similar to Western critical education: students' and teacher's collaborative learning, the unity of knowing and doing, the reflection on teaching and learning, and the building of societal transformation of humanity. They are also highly related to Marks and Eilks' (2009) socio-critical and problem-oriented instructional model for science education. Obtaining knowledge by investigating things (*ge wu zhi zhi*) is an important concept of (Neo-)Confucianism connected with ideas of scientific spirits and inquiry (Zheng & Wang, 2021) and a way of sincerity (*cheng*). Individuals finish their inter transformation by self-cultivation and character-building and then take responsibility to reach societal harmonism and transformation as the finial education goal in a moral way under Confucian culture (Zhao, 2013), while Western critical education encourages individuals to directly question and change the social environment to reach democracy (Giroux, 1985). So authorities' supports might facilitate students' pro-environmental behaviors and motivate students' engagement in the discussion about SSIs.

4 Conclusion

The United Nations (UN) suggest by 2030

> [ensuring] all learners acquire knowledge and skills needed to promote sustainable development, including among others through education for sustainable development and sustainable lifestyles, human rights, gender equality, promotion of a culture of peace and non-violence, global citizenship, and appreciation of cultural diversity and of culture's contribution to sustainable development. (see Goal 4.7: UN, 2015, p. 17)

This overarching political goal should influence educational practices in all countries, among them those having a background in Confucian culture and tradition. It is, however, necessary to note that the international discourse on education for sustainability in science education is basically dominated by Western modern views, at least when it comes to questions of science, technology, and the environment. More recent discussions nevertheless emphasize the importance of respecting non-Western worldviews on science more thoroughly in science education (Zidny et al., 2020).

Science education in China has been localized with disadvantages and/or advantages of Confucianism accompanying the development of Chinese industrialization in recent decades. As the awareness of the side effects is increased, the traditional anthropocosmic view of nature and humans (*tian ren he yi*) including Confucian values is being withdrawn. *Tian ren he yi* might be considered an important contribution for the global education community to enrich education for sustainability (Tu, 2001). Many (Neo-)Confucian values and ideas are in line with the philosophies of education for sustainability or ESD. Since most industrialized societies are built upon scientific knowledge and technology based on a Western modern scientific way of thinking, comparison, tensions, and connections of Western and Eastern cultures should be concerned in science education, including the fissions that potentially exist (Ogawa, 1986, 1989).

This paper provides an analysis of the research literature on science education for sustainability in Confucian culture with reference to the international discourse on education for sustainability. The discussion in this paper shows many parallels between Confucian thoughts and values and Western educational theories, e.g., in the concept of *Bildung*, when it comes to sustainability issues. Many connections were identified between Confucianism, education for sustainability, and selected concepts from Western education. Respect for nature and more holistic thinking in systems are essential components of both Confucianism and contemporary concepts of sustainability. These parallels provide a chance to enrich science education in Confucian societies by reflecting on developments in science and technology from both the political agenda for sustainable development and the values of Confucianism. From this comparison, the view of nature and humans can be considered a good link for Chinese science education to foster skills by education for sustainability. It is, however, important that curriculum development and research are needed in science education on how to better operate the combination of learning science with ESD in mainland China and other Asian societies, and Confucian views are related to both of them. To support this endeavor, a framework is suggested that aims to guide this process.

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Declarations

Competing Interest The authors declare that they have no conflict of interest.

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Paper 3

A case on a lesson plan about takeout plastics use addressing Confucianism for sustainability-oriented secondary chemistry education in mainland China

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A case on a lesson plan about take-out plastics use addressing Confucianism for sustainability-oriented secondary chemistry education in mainland China

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ABSTRACT

Socio-scientific issues-based science instruction addresses societal-related issues to promote contemporary science education. Societal-related issues almost always have to be considered in the cultural environment to which they are relevant. This means that the cultural aspects of socio-scientific issues need to be taken into account to develop scientific literacy for a sustainable future. However, related educational researches focusing on the cultural components in socio-scientific issues are rare in mainland China and elsewhere. A lesson plan about disposable plastic take-out food containers is presented that operates links to Confucian ecological ethics. The lesson plan was designed, implemented online due to the Covid-19 pandemic, and evaluated in a suburban High School in Beijing, China. The intervention contains the introduction, learning about conventional and biodegradable plastics, and a role-play debate to raise students' awareness of environmentally friendly attitudes and behaviors in connection to Confucian ecological ethics. Two learning groups (N=79) joined the intervention. A feedback questionnaire indicates the feasibility of the lesson plan and that focusing on Confucian ecological ethics can contribute to chemistry education for sustainable development in Confucian societies.

GRAPHICAL ABSTRACT

KEYWORDS

chemistry education, education for sustainable development, Confucianism, plastics use

INTRODUCTION

Modern societies are permeated by developments in science and technology. Life of humankind in current emerging and industrialized societies, however, causes many side effects on the global planet, e.g., climate change, biodiversity loss, environmental pollution, etc. Research and international policy advocate humans take better responsibility for and decline negative impacts on the natural world. One way suggested is to change education to better prepare the future generation to become responsible citizens. [1, 2]

One change in education suggested is Education for Sustainable Development (ESD). ESD is coined to highlight the role of all kinds of educational settings in fostering learners with decision-making ability and rational actions towards sustainability. ESD aims to equip learners with knowledge and skills to develop awareness of sustainable development ideas, benign attitudes and behaviors, and respect to ecological as well as economic feasibility, and societal justice.[3] Currently, the global aim in the *Agenda 2030* by the UN calls for: "*By 2030, ensure that all learners acquire the knowledge and skills needed to promote sustainable development, including, among others, through education for sustainable development and sustainable lifestyles…*" (p. 17).[4]

Among many other fields, chemistry (or science) education is called for to significantly promote ESD for a sustainable future.[5] Many theoretical and practical resources have been suggested for raising students' sustainability-related abilities in chemistry education, e.g., on the secondary educational level, during the last 20 years around the world. [6, 7, 8] Also, China has started introducing ESD in secondary chemistry education; however, ESD implementation in China is not yet very broad.[9]

Cultural aspects have gradually gained attention from researchers in science education, especially in non-western societies.[10, 11] Part of this work concerns the connection of non-Western philosophies with sustainability thinking for the purpose of education in general, and respecting the local philosophies and wisdom as a contribution to ESD in science education in particular.[12, 13] In China, Confucianism is one of the most influential traditional cultures originated by the Chinese teacher, philosopher, and politician Confucius (551–479 BC). Confucianism is an influential philosophy all over East Asia, such as in mainland China, Taiwan, Hong Kong, Macao, Korea, Japan, Vietnam, Malaysia, and Singapore. Confucian ecological ethics calls for humans harmoniously and peacefully living with all the other creatures in the world.[12, 14]

According to Li et al., [12] there are many connections between Confucian ecological ethics and theories of sustainable development, e.g., between the integration of the Confucian idea of the unity of nature and humans (*tian ren he yi*) and systems thinking approaches as a core competence in ESD.[8] There are also connections between Confucianism and modern interpretations of scientific literacy. Connections for promoting ESD in science education in Confucian societies were discussed to reinforce ethical and cultural perspectives in Vision III of scientific literacy (a critical and eco-reflexive vision) as suggested by Sjöström and Eilks.[15] ESD, Confucianism, and Vision III of scientific literacy all aim to foster students' responsible and benign attitudes and actions,[15] by values-driven and Bildung-oriented science education.[16]

Socio-Scientific Issues (SSI)-based science instruction is considered one of the most promising instructional models for ESD in chemistry education. [5,7] It brings global and local societal-related issues into chemistry classrooms addressing scientific knowledge and understanding the implications of its application. Talanquer et al. [17] highlight the importance and urgency of SSI-based instruction in chemistry education for confronting students with issues in a complex, uncertain, and changing world.

SSI-based science instruction plays a vital role in fostering students' critical thinking, argumentation and decision-making skills, and moral action[17] to promote students' social and ecological participation skills for citizenship and democracy education.[18]

Research and interventions on ESD-focused instruction linked with Confucianism in chemistry or science education are still rare.[12] This study aims to help closing the gap. The case presented here inquires into the potential role of Confucian ecological ethics in Chinese secondary school chemistry teaching for ESD. The SSI chosen for the intervention is the debate about a ban on the single use of nondegradable take-out plastic food containers in mainland China. The questions behind this case are whether the enrichment of ESD by including Confucian ecological ethics can positively affect students' learning along the controversial case of take-out plastic food containers. The two main research questions are: 1. Is the inclusion of SSI-based chemistry education perceived by secondary school students in China as an enrichment in the chemistry curriculum? 2. Is the inclusion of Confucian ecology ethics into SSI-based chemistry education perceived by secondary school students in China as a valuable contribution to promoting ESD?

BACKGROUND

The context of plastics use in take-out services in mainland China

In the 20th century, plastic products have been commonplace in many societies, for their less expense and density, marvelous versatility and durability, and better properties than other materials.[20] Until now, more and more plastic products have been manufactured and consumed. Unfortunately, more than half of them are disposed of in the natural environment causing the annual mortality of millions of marine creatures and soil and water pollution, which are mainly packaging plastic products for short lifetime use.[21]

China has become an industrializing country with rapid economic development and rising quality of people's life since the establishment of China's Economic Reform and Opening policy in 1978, especially during the previous two decades. China has turned into the world's largest country for producing and consuming plastics.[22] Electronic commerce, as an emerging industry, has sharply grown and developed along with prodigious economic benefits and employment opportunities in the digital age of the 21st century. For instance, online shopping and online food ordering have become young adults' mainstream lifestyle for their convenience in most Chinese cities since 2010.[23] The number of online takeaway food service users rapidly increases by 50 million per year (Figure 1) during the previous six years.[24, 25] This trend causes a vast amount of plastic waste, mainly from plastic food containers,[22, 25] which are rarely recycled due to contamination with oil and being considered of low economic value. Taking 2020 as an example, 17 billion orders of takeaway food, an average of 113 million plastic food containers used daily, generated 1.6 million tons of plastic waste in mainland China.[26] The Covid-19 pandemic additionally contributed to the increase in the consumption of take-out food since 2020 (Figure 1).

Figure 1. The number of total users of online food delivery services in mainland China (2016-2021)[24, 25]

China has released several strategies for reaching sustainable development, following the related policies from the UN. The Chinese Government raised and promoted the idea of ecological civilization construction in the 2010s. It suggested an overarching system of achieving harmony among humans, society, and the natural environment, connecting sustainable development and Chinese political and cultural aspects.[27] The plastic pollution issue has gained the attention of the Chinese Government since the late 2000s, with a series of policies implemented.[28] However, other than the European Union (EU), a general ban on single-use plastics for food delivery is not yet in operation. The EU[29] released the *Directive on Single Use Plastics*. It banned single-use plastic cutlery and expanded polystyrene and oxo-degradable plastic food containers in EU markets; it advocated reducing disposable plastic food container use either on the spot or takeaway from 2021. The EU directive led, e.g., to the German

Government banning the use of disposable plastic food containers and requiring reusable packaging in catering services or to-go orders from January 2023.[30]

This international trend also catalyzed China's release of the prohibition and limitation use policy of nondegradable disposable plastic products in the takeaway food industry with a clear goal and timeline in January 2020. The policy started prohibiting nondegradable plastic packaging bags used in food delivery services at and above prefecture levels of cities and some coastal counties by 2022. The manufacture and sale of expanded plastic tableware were banned by the end of 2020. It also stipulates that the use of nondegradable disposable plastic tableware in the food delivery industry should decrease by 30% at the end of 2025. Moreover, the Chinese Government highly recommends bio-degradable disposable plastic take-out food tableware as a prior alternative of nondegradable products.[31] The transformation process is ongoing; it is, however, not totally implemented in fact, neither in the EU nor in China – and even less in many other regions and countries in the world.

The policy raises public arguments about using and regulating nondegradable disposable plastic products. Players in the public debate come from environmental protection agencies, takeaway food restaurants, packaging industry, politicians, manufacturers of biodegradable plastic take-out food containers, etc. It is also suggested as an option that no cutlery is provided to customers by leading food delivery online service platforms, and cutlery in China is mainly chopsticks made of wood or bamboo. The arguments of using conventional plastics instead of bio-degradable plastic-based products are the higher costs, the less competitive use properties of biodegradable plastics, the questionable biodegradability without the appropriate post-treatment equipment, the doubted safety of use, the not yet known environmental impacts, etc. Nevertheless, in late 2021 the Hainan provincial government announced a ban on nondegradable disposable plastic products in take-out food services in Hainan, China.[32]

The scientific aspect of plastics use issue in take-out food service

Polypropylene (PP) take-out food containers account for more than 65% in all take-out food containers, making more than 95% in some cities of China.[26] The containers are mainly used for Chinese hot cuisine with highly oil and water-contained features. Other containers are made from polystyrene, paper, or aluminum. PP, as conventional plastic, has good chemical strength and heat resistance, with microwaveable and suitable moisture and gas barrier properties.[33, 34] It is safely and widely used in daily packaging, clothing, automobiles, transportation pipelines, etc., with excellent performances in use, low density, and costs.[20, 33] Otherwise, PP is difficult to degrade, and the degradation time in nature is about 20-500 years. Mismanaged PP food container waste could deadly threaten the lives of the creatures if they swallow them by mistake. What's more, the raw material of PP production is crude oil. Even though the consumption of crude oil in conventional plastics production takes a small part of the total crude oil expenditure, the amount of crude oil probably can only satisfy the needs for the following 50 years as a non-renewable resource.[20] China is also a country that lacks natural crude oil resources. The consumption of a large amount of disposable PP food containers does not benefit China in its sustainable development.

Polylactic acid (PLA or polylactide) is one of the most representative biodegradable plastics used as alternative in take-out food containers.[20] Biodegradable plastics can be degraded into small molecular fragments and then degraded by microorganisms.[34] PLA can be derived from renewable resources, i.e., by the fermentation of starch or sugar feedstocks,[20, 35, 36] such as corn in China. Thus, PLA is suggested as an environmentally friendly alternative to reduce conventional plastic waste, when used in food packaging, medical, textiles, automotive and agricultural areas. It has been increasingly used since the late 2000s.[20, 35-37] PLA has reasonable mechanical strength, is biocompatible, and provides stiffness and moderate gas barriers, accompanied with the weakness of brittleness and low heat resistance.[35, 36]

The best way for PLA product degradation is industrial composting under certain conditions, such as a temperature of around 58℃ and specific amounts of oxygen and water. This way, PLA can be degraded with more than a weight loss percentage of 85 % in 3-6 months. By contrast, PLA nearly has no change after one year in natural environments, such as fresh or seawater. Under home composting, the degradation of PLA during one year is also not satisfying.[38, 39] Furthermore, some researchers[40] recently found that animals more actively digest PLA microplastics than conventional plastics; however, it also causes several adverse effects on animals' digestion systems. In other words, if PLA products are discarded in the natural environment, they also result in environmental pollution and might threaten creatures. So far, there is generally no suitable treatment equipment for PLA waste in Chinese municipal waste centers. Additionally, the price of PLA is around four times higher than PP. The higher density of PLA also increases the cost of PLA use than PP products in the same area, even though the Government might provide financial support.[41]

As mentioned above, PLA food containers are suggested to face the problems of lower heat resistance, food crisis, cost, and controversial degradability without the appropriate end-of-life treatment. These points are the main viewpoints from opponents of popularizing PLA food containers in China. However, some supporters have positive views about the promising development of PLA with scientific and technological improvement and the government policy. It is in line with international controversial views about PLA use, such as *against* from the EU[29] or Germany[30] because of its slow biodegradability, prices, etc.

ESD and plastics use in chemistry education in mainland China

The current Chinese chemistry high school curriculum standards by the Ministry of Education of the People's Republic of China [MOE][42] highlight the societal aspect or context of chemistry education for promoting ESD, compared with the previous versions of the standards.[43] The standards suggest five core competencies: *1. macroscopic identification and microscopic analysis; 2. changes and equilibrium; 3. evidence-based reasoning and modeling; 4. scientific inquiry and innovation; and 5. scientific attitude and social responsibility.* Under 5. the standards suggest the students to (p. 4): [42]

> *... have sustainable development awareness of resources saving and environmental protection, to form a simple, moderate, green and low-carbon lifestyle from individual actions; have the ability to take the proper value judgment about social hot, chemical-related issues, and to carry social practice activities about chemical issues.*

However, according to Li and Eilks,[9] secondary chemistry education for ESD is still at the initial stage. Due to the examination-oriented feature of Chinese education, there might also be many barriers to further implementing ESD. This is why the current study tried to identify ways to foster societal-oriented chemistry education by combining ESD with Confucian ecological ethics.

The vast uncontrolled PP plastic wastes from food delivery service violate Confucian ecological ethics and impede the sustainable development of Chinese society. The question *for* or *against* conventional plastic food containers can be raised as a controversial issue in chemistry education by an SSI approach. Arguments and debate will concern questions from science and technology, as well as ecology, economy, society, policy, and culture. According to Liu et al.,[28] the legislative policies are only the beginning stage for establishing environmental friendliness. Further steps have to include education as the most significant way to solve the plastics pollution problem by changing attitudes and behaviors to bring back harmony between humans and nature, as outlined in the central ideas of Confucianism.

DESIGN OF THE LESSON PLAN

Overview

The intervention aims to nurture Chinese high school students' sustainability awareness through SSI-based instruction in connection to Confucian ecological ethics. The plastic takeaway food container use issue is currently, vigorously and continuously discussed in China, related to economic, societal, and environmental aspects. Understanding the issue needs chemistry knowledge, i.e., about the properties, the synthesis, and the degradation of PP and PLA. High school students also should be fostered with sustainability competencies such as systems thinking, anticipatory, action, communication, and normative competences.[44]

One way to contribute to Vision III of scientific literacy, which underlines the value and moral function of science education, is emphasizing local culture and wisdom.[12,16] Some core ideas of Chinese Confucian ecology ethics, such as benevolence, harmonism, and harmony between humans and nature (see more detailed explanations in Li et al.[12]), are briefly integrated into the lesson design.

The viewpoints about the takeaway plastic food containers issue are included to create a real context from Chinese society and its public media. The structure of the course contains four stages shown in Table 1. It includes the introduction of the course by bringing the plastic takeaway food container issue for engaging students' learning. It is followed by learning about the scientific background of PP and PLA use, a debate about conventional plastic takeaway food container ban or not, and a reflection about the lesson plan. Due to the COVID-19 pandemic, the course was designed for online learning. Table 1 provides an overview about steps and activities. Further details are discussed in 3.2.

Table 1. The structure of the lesson plan on plastics used in take-out food service

Stage	Content	Purpose	Media and learning
Introduction (45min)	• Overview • Plastics use data in take-out food service • Plastic pollution video • Plastics use policies in mainland China • A critical article on biodegradable plastics	Presenting the SSI, providing background information, and introducing the controversy	Online conference tool with collaborative learning phases, presentation, datasheet, video, article
Scientific background (90min)	Historical development of biodegradable plastics Comparison of properties between PP and PLA Synthesis of PLA experiment Degradability of PLA experiment LCA of PLA and PP food containers	Understanding the scientific background behind the use of conventional and biodegradable plastics	Online conference tool with collaborative learning phases, presentation, videos, worksheets
Debate (45min)	moderator Confucianist Chemist *(studying conventional plastics)* Biodegradable Disposable Plastic food container manufacturer Environmental organization agent Government official Restaurant *(with a takeout service)* manager	Understanding the complexity of chemistry-related SSIs, the potential role of Confucian ecological ethics for sustainability ideas, and fostering students' decision-making, argumentation, and social responsibility skills.	Online conference tool with collaborative learning phases, worksheets for role play preparation, role play introduction and with tips, evaluation rubric for the debate
Reflection (15min)	Questionnaire on students' interest, perception of relevance, and perspectives about the role of Confucian ecological ethics in science education, etc.	Reflection and assessment of students' learning and perception of the lesson plan	Wenjuanxing *(online questionnaire platform)*

The lesson plan in detail

Introduction

The lesson begins with the introduction to the topic, including the outline of the intervention, behavior rules, learning methods, and evaluation tools. To introduce the topic, a short-edited video about plastic pollution is used: *How much do we know about the ubiquitous micro-plastics?* (Original video link: https://open.163.com/newview/movie/free?pid=XGTHV3F3B&mid=KGTHV3F47). The video refers to Chinese policies on disposable plastics use in takeaway food service, mentioning biodegradable plastics substituting conventional plastics as one potential solution for plastic pollution. An excerpted critical news article is read: *Plastic, it's not easy to say I love you* (Original text link: https://www.lifeweek.com.cn/article/124787). The article questions biodegradable plastics to bring the controversial issue for or against the ban on the use of nondegradable disposable plastic food containers in online take-out food services into a discussion. Students read this article in small groups with guiding questions about the main ideas of the article, writing down their questions about biodegradable plastics, and their thoughts about the former controversial issue, where the definition of sustainable development and Confucian ecological ethics are briefly referred to. These are for collecting students' prior knowledge and attitudes about biodegradable plastics, as well.

Scientific background

Clarifying the scientific background contains five learning activities to be done by the students in groups in self-organized group work. The activities focus on chemical background knowledge and life cycle assessment (LCA) of PLA and PP food containers in mainland China. Students learn and discuss the related worksheets with guiding questions in small groups and then share their ideas with the whole class. The five learning activities encompass the historical development of bio-degradable plastics, a comparison experiment of properties between PLA and PP, an experiment on PLA synthesis, one experiment on PLA degradation, and the LCA. The activity on LCA is implemented to foster students' systems thinking competencies.

To implement the LCA (Figure 2) of single-use PP and PLA take-out food containers in China an analysis was carried out by the LCA software SimaPro 9.3 (the software link: https://simapro.com/licences/#/education). The corresponding data was obtained from related published research articles. The LCA uses three impact categories: human health damage, ecosystem damage, and natural resource consumption. Students are required to compare, analyze and describe the LCA results of the food containers to understand their environmental impacts. The results of the LCA in comparison are presented in Figure 3. Questions on similarities between systems thinking and Confucian unity of humans and nature [12] are also included. In general, LCA is a relative tool, but decision makers also need to think about other aspects besides environmental impacts, such as social, economic, cultural, and scientific factors.[7, 12, 44] These aspects are put in the following role-playing debate.

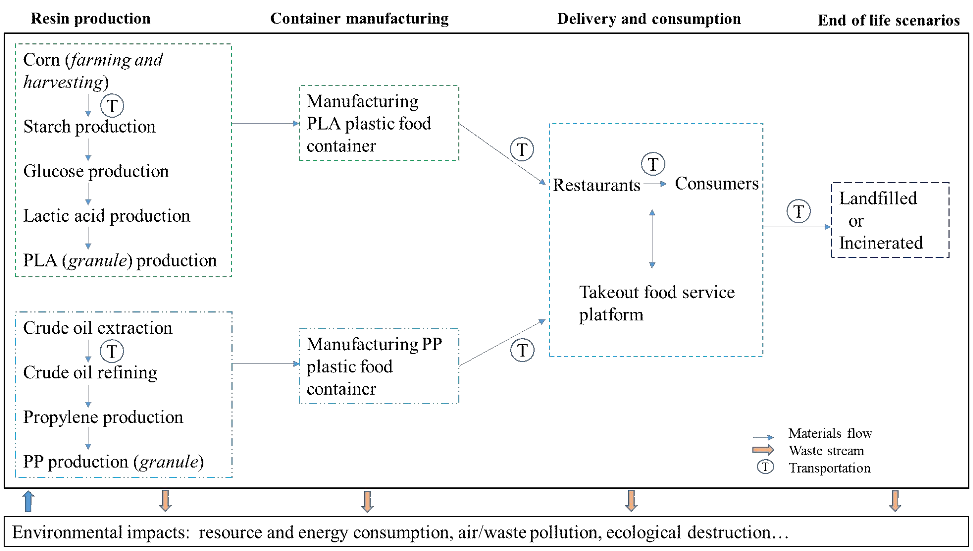

Figure 2. Life circle phases of disposable PLA and PP food containers for the take-out food industry in mainland China [26, 46]

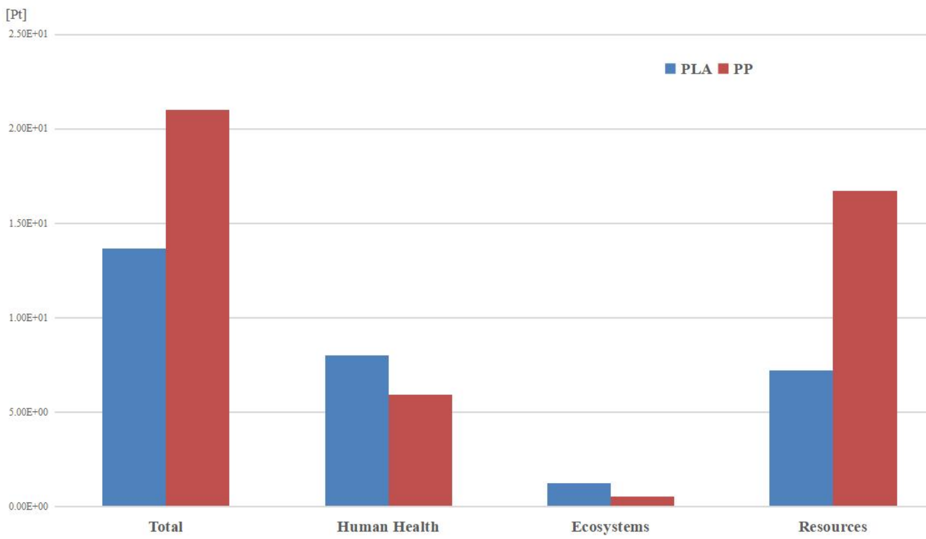

Figure 3. Relative comparison of LCA analysis results for single-use PLA vs. PP take-out food containers in mainland China.

Debate

The design of the role-playing debate was inspired by Lopez-Fernandez et al.[47] It consists of an introduction, task, procedure, evaluation and conclusion with detailed information and guidelines, referring to the learning mode of a WebQuest.[48] The debate topic is for or against "ban on use of disposable nondegradable plastic take-out food containers". There are seven roles in the debate. First, it is the moderator of this debate who plays a vital role in its smooth and efficient running. The other roles are: Confucianist, restaurant manager with take-out service, government official, chemist working on traditional plastics, biodegradable plastic food container manufacturer, and environmental organization agent. Their role descriptions and positions on the use ban of disposable conventional plastic food containers in take-out service are provided, according to the context of mainland China as represented in the public media.

The learning materials contain a checklist for each role, role descriptions, main ideas of the roles, recommended websites, suggestions for a debate, and rubrics of the debate. The moderator should know about the main ideas of each role and learn the related content of the role of a Confucianist for highlighting Confucianism. The role play starts with presenting statements. The moderator kicks off the debate (2 min) and introduces it, and each role presents their main ideas of the debate topic for 1 minute. In the second stage, each role has 5 minutes to revise and supplement arguments and questions, according to the opposite side's statement, with their group members' assistance. The third stage is a free debate for about 20 minutes. The pro side starts to speak, and then the con side answers, including questioning, replying, and refuting. The moderator takes responsibility of smoothly facilitating and promoting the debate by avoiding conflicts, clarifying misunderstandings, asking questions, and summarizing sides' statements, including making all roles participate in the debate. The audience may raise more questions, answered by certain roles (2 minutes). At last, the moderator summarizes the debate (1 minute). After the debate, all the students take their position on the debate. The instructor and students further evaluate the debate.

Reflection

In the reflection phase, a survey was done by an online questionnaire platform. The reflection focused on the students' perception of the lesson plan in general, and the integration of Confucian ecological ethics with chemistry teaching in particular. Students were also asked at the beginning and end of the lesson plan on their position concerning a ban on disposable nondegradable plastic food containers in takeaway services to see any potential change.

Implementation of the lesson plan

The lesson plan was tested in two groups with a total of 79 10^{th} Grade students (15-16 years old; 47 males and 32 females, each group with 39 or 40 students) in chemistry classes. The implementation was online for the required policy of the Covid-19 pandemic in mainland China. The teaching was operated by Tencent meeting, with Prezi presentations, and WeChat for group discussions.

The intervention took place at a public school in the suburbs of Beijing, China, for two weeks in June 2022. It was taught by the first author. The implementation of the intervention was permitted by the principal of the school. The homeroom teachers of the 10^{th} grade communicated the study with the students' parents.

The students had already finished all the obligatory lessons for the 10^{th}-grade chemistry curriculum. From the lessons, students possessed fundamental knowledge about organic chemistry, such as alkanes, alcohols, and basic nutrient substances for human beings. They already knew about the concept of sustainable development, which is the theme of the last chapter of their 10th-grade chemistry textbook.

Every 5 or 6 students were randomly assigned as small learning groups in the class. Grouping was done by the teacher taking gender balance into account, and allowing slightly justified changes according to students' personal relations. In each group, one leader was assigned for convenient management and effective group working.

For the phase of the role-playing debate, students had one week to prepare in a homework assignment. Each group of students prepared one role, which the teacher randomly assigned. The students prepared and discussed the related content according to the corresponding role before the debate. In the role-playing debate, each group assigned one student to participate; others acted as counselors, evaluators, and audience of the debate.

Evaluation

As the lesson was finished, a feedback questionnaire was provided for students' reflection on the intervention. The feedback questionnaire consists of two open-ended questions and twelve 5-step Likert items. Students were asked to answer the open questions first, not to be biased by the Likert-items. The open-ended questions are about students' views about the course and their perspectives on the role of Confucianism and sustainable development for chemistry learning. The Likert items aimed at obtaining students' interest in the course, their attitudes about learning materials or content, the relevance of the chemistry curriculum, the instruction method, the complexity of chemical issues, and their views about the role of Confucian ecological ethics in chemistry education. Finally, 74 students filled in the questionnaire on a voluntary base. The questionnaire was analyzed by descriptive statistics and word cloud analysis (the website link: https://classic.wordclouds.com/), respectively.

FINDINGS AND DISCUSSION

The findings of the 12 Likert-questions are shown in Figure 4. According to the results, most students enjoyed and were interested in learning this topic, with around 70 % strongly agreed or agreed, and only very few students were disagreeing or strongly disagreeing in Item 1 and 3. This is in accordance with many answers to the open-ended question "What do you think about the lesson plan?", shown in Figure 5(a). The most frequent responses were (very) good, (very) interesting, (very) enjoyable or (very) creative, etc. Some students also stressed the practical work was innovative. Most students indicated they liked the lesson best with interaction and discussion with their classmates, debate, daily-life-related, innovative, or practical features. They also thought this lesson was different from their previous chemistry course. For example, in two quotes, students said: "*This lesson was excellent. I liked the debate best and learned a lot." "This lesson was outstanding. It was quite different from my chemistry class before, which only focused on chemistry knowledge, rather than this with a daily-context chemistry*".

This positive perception, in general, was reflected also in the question if the lesson was considered relevant to the chemistry curriculum, with more than half of the students agreeing and less than 10 % disagreeing (Item 4). Three quarters of the students agreed that their awareness raised how complex decisions on chemical issues in society are, again less than 5 % disagreeing (Item 6). Most of the students gave feedback that this topic is an excellent way to know the thinking of the public about a chemical issue. As such, one student said, "*This lesson was different from my previous chemistry study. The previous chemistry class focused more on the content from the chemistry textbook, which was proved by using examples. This lesson uses examples to deal with and test authentic issues in our life.*" A similar picture also appeared concerning students' perception of skill development (Item 9), raising attention (Item 12), or provoking open-minded thinking (Item 8). The only item difference was whether chemistry education should only focus on the fundamentals of chemistry and leave out other aspects (ecological, economic, social, and cultural). In Item 5, the picture was split with about one-third agreeing and one-third disagreeing. These mixed attitudes might imply the high stress on chemical knowledge in Chinese chemistry exams.

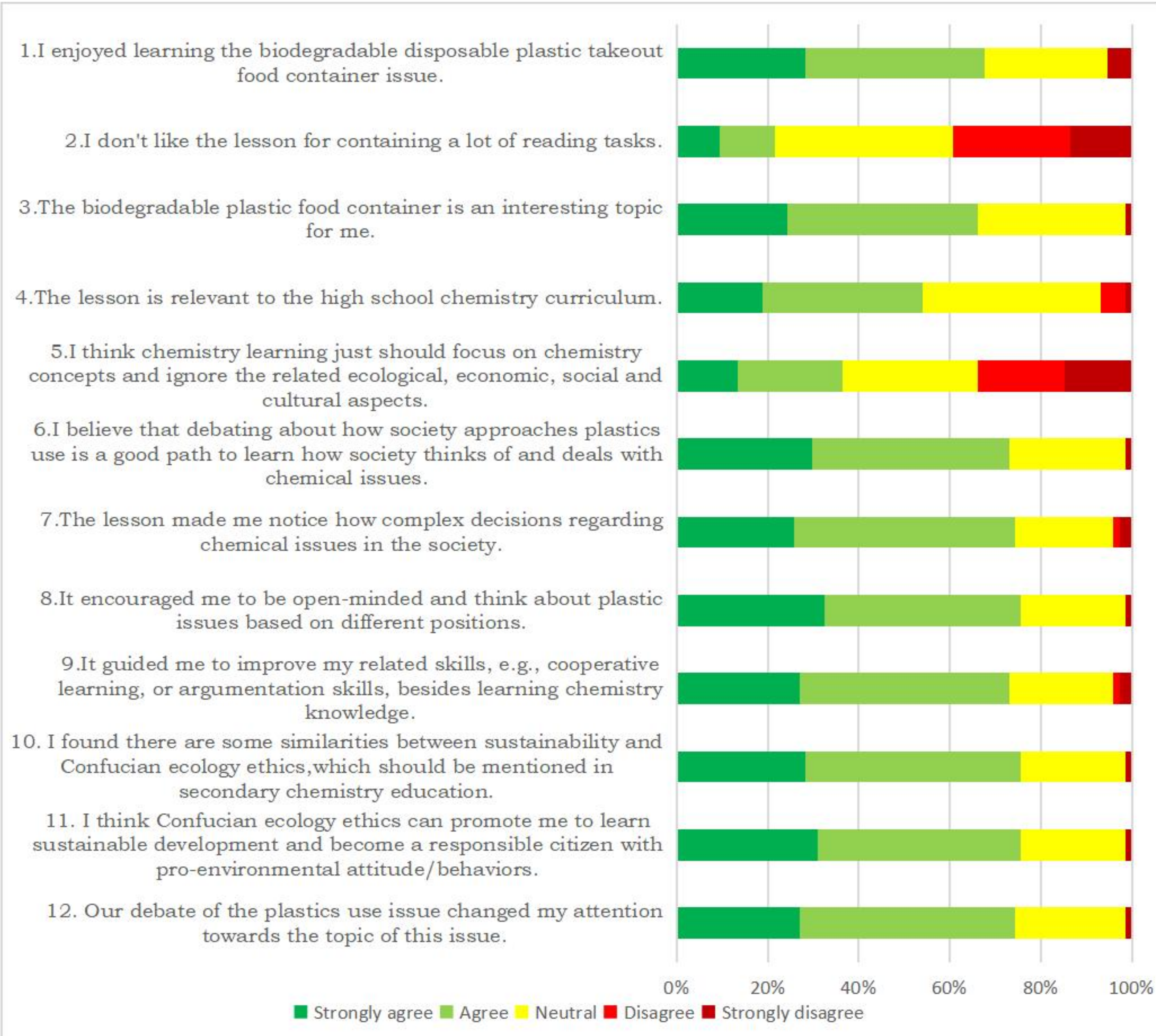

Figure 4. Students' feedback in the Likert-questionnaire (N=74, no answer N=5).

(a) (b)

Figure 5. The word cloud results from students' feedback on the lesson plan (a) and their views about Confucianism and sustainable development for chemistry learning (b).

A specific focus of this intervention was on combining the implementation of SSI-based instruction with Confucian ecological ethics. Almost all students (around 75% with agreement or strong agreement, another 20 % neutral) realized, at least to a certain extent, the similarities between Confucian ecological ethics and sustainable development (Item 10). They support the claim that learning about Confucian ecological ethics has potential in the context of chemistry education to promote them to learn about sustainable development and to become a responsible citizen with pro-environmental attitudes and behaviors (Item 11). It is consistent with Kim and Roth's[49] findings. They pointed out that Confucian ecological ethics can assist SSI-based science education in promoting students' awareness of the unity of knowing and action related to environmental issues.

The results from the Likert questionnaire were also mirrored in the second open-ended question about the students' views on Confucianism and sustainable development for chemistry learning (Figure 5(b)). Most of the students acknowledged the positive contribution of Confucian ecological ethics to chemistry learning for sustainable development. They thought Confucianism, sustainable development, and chemistry learning are interconnected, mutually and interactively supportive, and complete each other. In other words, they think the integration of ESD and Confucianism in chemistry learning can facilitate their benign behaviors and responsibility to reach harmony between humans and nature. One student wrote: "*I think their relationship among Confucianism, sustainable development, and chemistry learning is complementary and inseparable. Only as each step done comprehensively, can the environment be protected and better results be achieved.*" Another student elucidated: "*Confucianism and sustainable development are tightly interlinked, and chemical learning with Confucianism assists in achieving sustainable development ideas.*" Some students also indicated that these connections provided a different view. One student also said the link among them had both negative and positive sides, and one should consider them rationally.

Over the lesson plan, the supportive percentage of a ban on disposable nondegradable plastic food containers in takeaway services increased from 78% to around 90%, respectively, at the beginning and end of the class. In the beginning, the *for* side was mainly concerned about the time for the degradation of conventional plastics and environmental protection; otherwise, the *against* side was primarily worried about questioning the environmental friendliness of biodegradable plastics and their high prices.

The results of this case study are in parallel with some other cultural science education research in non-western societies. Aikenhead[50] found science education, immersing environmentally friendly values of the *Maori* culture, could provide plural and inclusive perspectives about nature for students, including acknowledging the meaningfulness of the local culture. It also motivated the students' lifelong learning and awareness of the harmony of the Earth. This case study also supports Khupe's[51] assumptions of the value of indigenous knowledge systems for science education where role-playing activities provide access to diverse viewpoints related to the local culture.

CONCLUSION

In previous educational reforms, Chinese secondary chemistry education primarily focused on the rote acquirement of chemistry knowledge for its exam-oriented educational system. The latest round of educational reform, however, brought the chance to highlight societal aspects and skill-oriented teaching to develop higher levels of scientific literacy, namely Visions II and III of scientific literacy as discussed in Sjöström and Eilks.[15] SSI-based chemistry or science instruction is a suitable mode for fostering the ability of decision-making, argumentation, and independent thinking by students' dealing with complex, controversial issues.[52] But, new forms of education also face many challenges for limited class time and exam orientation. Nevertheless, to come up with the philosophy of the current educational standards, teaching approaches and methods need to be modified. It is suggested that this has to consider the context of Chinese society, for instance, the upcoming debates about SSIs as represented in public, in traditional or new media. As such, a topic and approach presented in this article tries to fill the gap. With its connection to an authentic and current controversial public debate and Confucian ecological ethics, it presents a promising case and strategy that promote ESD in Chinese chemistry education.

All in all, students' feedback, assignments, and behaviors in the class demonstrated their interest in this topic. Most of them were satisfied with the structure and content of the lesson. For instance, the representation of practical work motivated them to learn more contents about the degradation of

PLA. From their perception and the teachers' observation, the students' ability of communication and attitudes of environmental friendliness were improved, at least to some degree. The students also showed interest in the topic and the role-playing debate phase. Last but not least, most students agreed with the positive potential of integrating Confucian ecological ethics into chemistry education in mainland China to promote ESD.

Due to the time limitation, and the implementation of only two weeks, implementation in one school with a limited number of students and a few of class periods, the results in this case have some limitations, and a more detailed study is needed in the future. However, the clear tendencies indicate the potential brightness of implementing SSI instruction connected to Confucian ecological ethics for ESD in Confucian societies to promote students' knowledge and positive attitudes.

The new curriculum standards added societal aspects to the chemistry curriculum. It seems there is still a long way to go for teachers to transfer the goals of chemistry education. To help teachers, further curriculum development and research are needed. Additionally, the most influential factor, the examination regulations, might be changed, which would assist in implementing more societal aspects into Chinese chemistry education. To make this lively for students, this should be done with a focus on the context of Chinese societies and the influence of the cultural aspects within them.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.XXXXXXX. [ACS will fill this in.] Example brief descriptions with file formats indicated are shown below; customize for your material.

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Supplemental materials for the case study I: "*A lesson plan about takeout plastics use addressing Confucianism for sustainability-oriented secondary chemistry education in mainland China*".

The following supplements contain LCA of PP and PLA single-use takeout food containers in mainland China, the descriptions of the roles in the role-playing debate, and the selected students' assignment results in this intervention to further present students' learning interest and some results for this dissertation.

Supplemental material: I
Life cycle assessment of PP/PLA disposable takeout food containers in Mainland China

Chinese takeout food industry is flourishing in economically developed metropolia (municipal and provincial capitals and cities specifically designated in the state plan), accounting for more than 50%. Significantly, the first-tier cities (e.g., Beijing, Shanghai, Guangzhou, and Shenzhen) take up the largest monthly takeout food orders. It brings economic growth and convenience to people's daily life but also causes a massive amount of plastic waste due to the low recycling rate of plastic waste. Chinese food contains oil, and it causes a high cost to clean plastic food containers. So one province in China banned disposable food containers, and the Government plans to decrease the usage amount of non-degradable food containers and advocate the usage of biodegradable ones. However, this policy is hot, argued by some environmental protectors, chemists, manufacturers, etc. Especially, the question is whether biodegradable food containers are more environmentally friendly than conventional plastic.

Hence, the life cycle assessment (LCA) of bio/non- bio-degradable plastic takeout food containers in China is carried out. The LCA software **Simapro 9.3** was used for the analysis, and the inventory library is Ecoinvent 3 allocation. ReCiPe Midpoint(H) V1.13/World Recipe H and ReCiPe Endpoint(H) V1.13/World Recipe H/H are used, respectively. Due to the lack of data from the Chinese Life Cycle Database (CLCD), the data is mainly from RoW, and some were adopted from the research literature.

There are some differences in the environmental impacts of the takeout food industry from city to city due to different waste treatment scenarios. The average delivery distance of takeout food orders and the overall trend of environmental impacts are quite similar. PP takeout food containers account for more than 65% of all takeout food containers, more than 95% in some cities in China (Zhang & Wen, 2022). PLA is one of the most representative biodegradable plastics in takeout food containers. So LCA of PP and PLA takeout food containers will take Beijing as an example.

The LCA of PP and PLA takeout food container is to evaluate the environmental impacts of these two kinds of food containers from the cradle to the grave and to assist further the decision to ban disposable non-degradable plastic takeout food containers in China. According to the existing research articles on PLA and PP plastics or food containers in China (Li et al., 2022; Luo, 2021; Meng, 2010), the most popularly used takeout food container is 650 ml and rectangle in China. The mass of one 650ml PLA takeout food container is 29 g, and the mass of PP is 23g. One thousand pieces of PLA or PP food containers are one functional group for analyzing LCA. The list of them is shown in Table S-1-1.

Table S-1-1 List of PLA and PP food containers (1000 pieces as one function)

Item	PLA	PP
One piece/g	29	23
Overall weight/kg	29	23
Raw materials: Crude oil/kg	-	43.71
Monomer: Propylene/kg	-	24.15
Raw materials: Maize/kg	65.25	-
Monomer: Lactic acid/kg	41.91	-

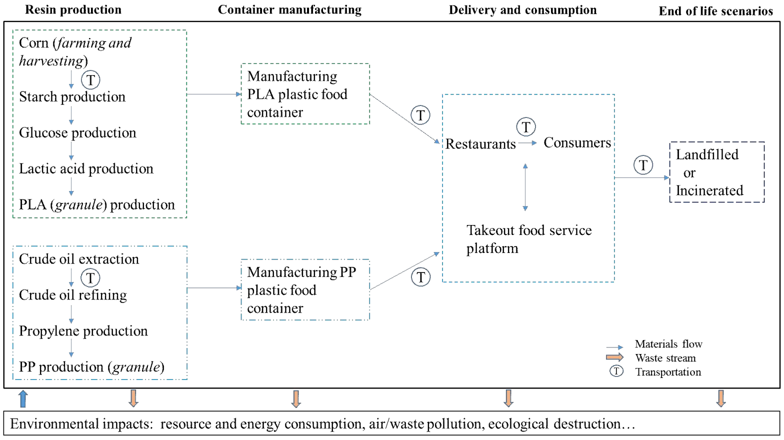

Figure S-1-1. Life circle phases of disposable PLA and PP food containers for the takeout food industry in mainland China (adapted from Madival et al., 2009; Zhang & Wen, 2022)

The inventory of the related processing unit from the stages in **Figure S-2-1,** including the description, was checked. Therefore, the processes of PLA takeout food container of one functional unit for the analysis, are maize grain [RoW] production Cut-off U, polylactide, granulate[GLO]production, cut-off, S, and Extrusion of plastic sheets and thermoforming, inline[RoW]processing, Cut-off, for the PLA resin production and container manufacturing. The production of PP takeout food containers includes propylene[RoW] production, cut-off, u. and Polypropylene, granulate[RoW] production, Cut-off, U. The manufacturing of PP takeout food containers is also Extrusion of plastic sheets and thermoforming, inline[RoW]processing, Cut-off.

Transportation and usage: The locations of the production of polymers and the manufacturing of plastics are hypothesized to be the same. According to Luo et al., 2021 and China plastic industry yearbook 2021, the location of the leading plastic manufacturing factories in China is Zhejiang province, including the largest PLA-producing and manufacturing company, Zhejiang Haizheng Co., Ltd. The delivery distance from Zhejiang to Beijing is 1250km, referring to Baidu Map, and the plastic products are shipped by 28t truck by the highway. The takeout food delivery is 2km by e-bike (Zhou et al., 2020). The usage of takeout food containers during the consumers' dining does not have obvious environmental impacts (Zhang & Wen, 2022). This stage used two processes from LCA software: The Energy use and operation emissions, electric bicycle[RoW]processing Cut-off, U and Transport, freight, lorry 16-32 metric ton, EURO 6, Cut-off, U[RoW] Transport.

The delivery distance for municipal solid wastes (MSW) is 28 km, according to Meng (2010). According to the current situation, there is no industrial composting for decomposing PLA, only treated by incineration or landfill in China. In Beijing, the ratio of incineration and landfill of MSW was 82:18 in 2020 (National Bureau of Statistics of China, 2021). The quite rare recycled PP food containers are also ignored. There is no available data for PLA waste treatment in Ecoinvent 3, so the data of mixed plastic wastes [RoW] will be used for PLA waste treatment. The collection of plastic wastes refers to Municipal waste collection service by 21 metric ton truck[ROW].

The related analysis of the life cycle of PLA/PP disposable takeaway food containers at the holistic process is shown in Table S-1-2. The explanation of the category indicators can be seen in Huijbregts et al. (2017). To readily compare the different impact category indicators, the results are normalized by the reference of an average annual environment impact per capita in certain areas (SimaPro, 2020), shown in Figure S-1-2.

Table S-1-2 The total environmental impacts of the cradle-to-grave of disposable PLA/PP takeaway food containers (*Characterised results at midpoint level*)

Impact category	Unit	PLA	PP
Climate change	kg CO2 eq	1.97E+02	1.60E+02
Ozone depletion	kg CFC-11 eq	7.83E-06	2.05E-06
Terrestrial acidification	kg SO2 eq	8.00E-01	3.38E-01
Freshwater eutrophication	kg P eq	1.59E-02	2.26E-03
Marine eutrophication	kg N eq	1.03E+01	2.88E-02
Human toxicity	kg 1,4-DB eq	8.66E+00	6.18E+00
photochemical oxidant formation	kg NMVOC	4.74E-01	3.56E-01
Particulate matter formation	kg PM10 eq	3.07E-01	1.54E-01
Terrestrial ecotoxicity	kg 1,4-DB eq	6.53E-01	1.10E-02
Freshwater ecotoxicity	kg 1,4-DB eq	6.15E-01	6.10E-02
Marine ecotoxicity	kg 1,4-DB eq	1.66E-01	9.77E-02
Ionising radiation	kBg U235 eq	5.13E+00	1.94E+00
Agricultural land occupation	m2a	5.71E+01	5.67E-01
Urban land occupation	m2a	2.37E+00	2.68E-01
Natural land transformation	m2a	5.94E-03	1.83E-03
Water depletion	m3	1.51E+01	8.48E-01
Metal depletion	kg Fe eq	2.90E-01	1.38E-01
Fossil depletion	kg oil eq	2.79E+01	8.30E+01

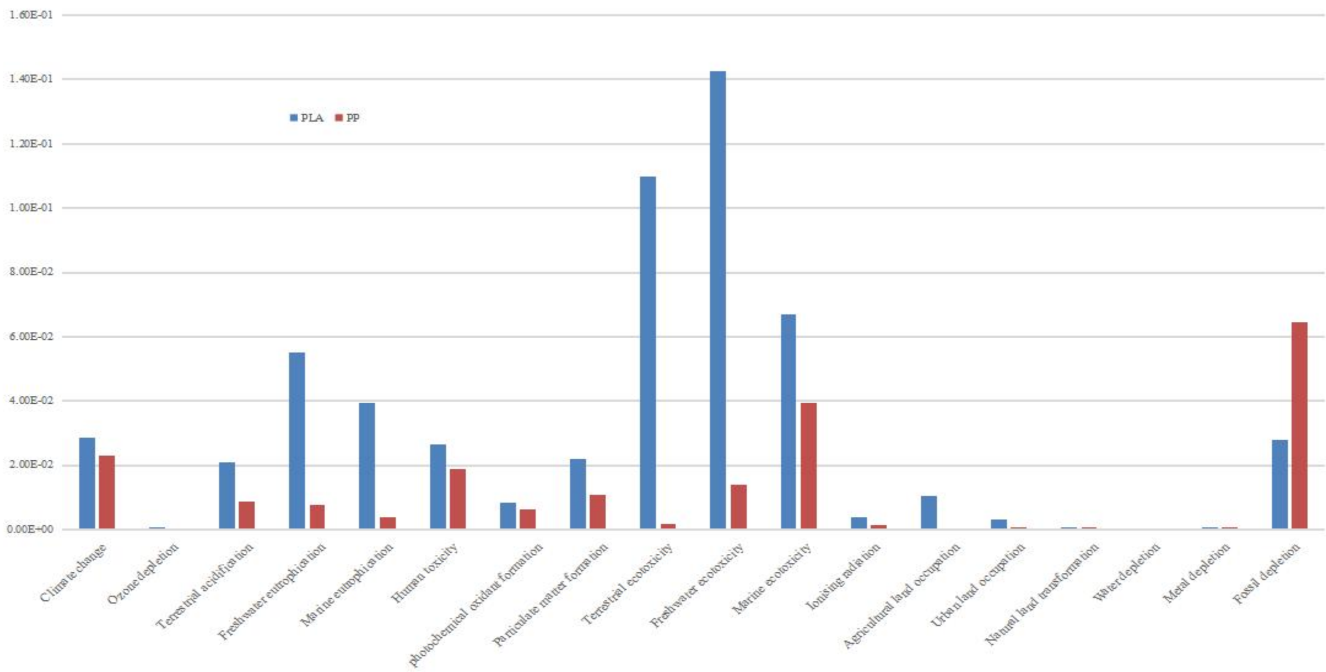

Figure S-1-2 Comparison of environmental impact indicators in the life cycle of disposable PLA and PP takeaway food containers (*normalized results at midpoint level*)

Furthermore, the related analysis at the Endpoint level method is clustered into three categories: human health damage, ecosystem damage, and natural resource consumption (non-renewable). According to the actual impact size of the above environmental impact indicators, the weighting analysis is shown in Figure S-1-3 to obtain the total environmental impact results of PLA and PP disposable takeaway food containers. The unit of Pt is a relative scale indicating the average annual environmental loads of one person in a particular area (Van den Bossche et al., 2010). The total assessment results are similar to the existing research (Chen et al., 2022; Moretti et al., 2022; Zhang & Wen, 2022; Zhao et al.,2022).

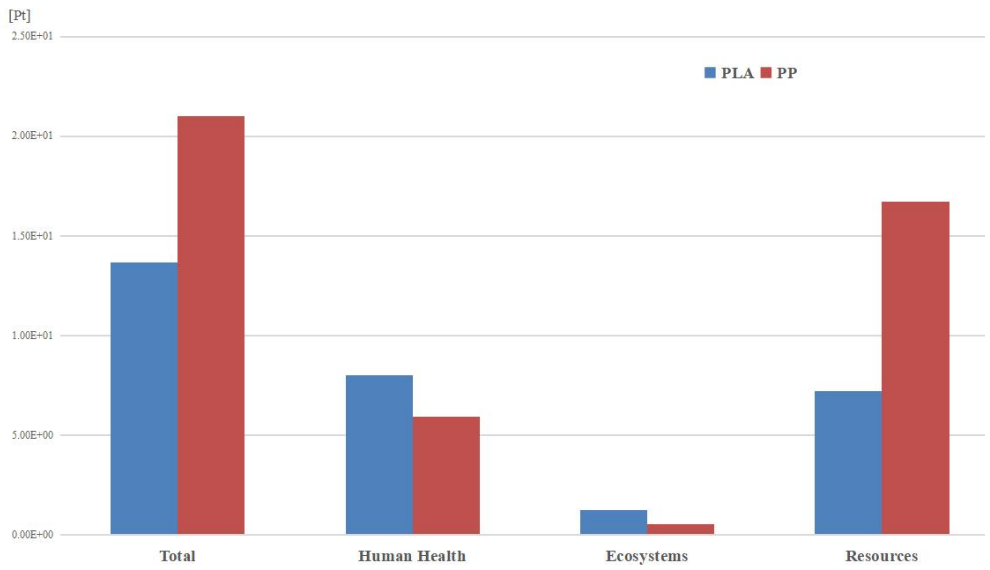

Figure S-1-3 Comparison of total environmental impact results of PLA and PP takeaway food containers in mainland China (*weighting result at the Endpoint level*)

LCA is a comparative tool for decision-makers to make informed decisions by analyzing the environmental impacts of one product. Besides the environmental impacts of one product or activity, other criteria, such as costs, chemical performance (referring to the learning station of the properties of PP and PLA), etc., also need to be considered for balancing all the effects for a sustainable society (Curran, 2008, p.2168).

The economic effect is also essential to sustainable development, except for social and ecological aspects, such as social justice and ecological integrity(environmental friendliness). Look at the prices of the food containers for Beijing restaurants in Table S-1-3, according to the most prominent Chinese wholesale online platform, 1688. To further discuss the sustainability of these two products.

Table S-1-3 The prices of disposable PP and PLA food containers

Disposable food Container (650mL)	Wholesale Price (RMB/1000 pieces)
PP	313
PLA	1175

Note：The prices include the shipping costs.

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Supplemental material: II
The Descriptions of Roles in Role-playing Debate

The descriptions of roles in the role-playing debate are shown in Table S-2-1.

Table S-2-1. The descriptions of roles in the role-playing debate of use ban of single-use conventional plastic food containers in the takeout industry

Roles (Position: pro)	Descriptions	Roles (Position: con)	Descriptions
Confucianist:	You are a well-known expert on Confucianism. Confucianism believes we should harmoniously live with all creatures in nature, caring for and loving them. Plastic pollution, such as single-use plastic food container waste, takes a significant risk to animals and causes the death of many creatures. Crude oil is quite limited, the raw material of conventional plastics. We should be frugal for the interests of our future generations as well.	A manager of a restaurant with takeout service:	You are a manager of a restaurant in Beijing that offers takeaway service. To maintain the sales of takeout food, you pay more attention to performances, safety, and prices of takeout food containers. PP food containers have a high safety performance, oil and heat resistance, microwave heating, and low cost. However, the price of a PLA food container is 3-4 times as high as a PP food container. Additionally, PLA cannot be used for hot food.
Government Official:	You are an official of the National Development and Reform Commission. The uncontrolled use of disposable non-degradable plastic food containers in the takeaway industry has caused tremendous pressure on the natural environment due to plastic pollution. For people's health, the establishment of ecological civilization, and sustainable development, you think that it should ban using disposable non-degradable plastic food containers, and biodegradable plastic food containers are suitable alternatives. For the high costs of bio-degradable plastic products, such as PLA, the Government will give relevant financial support to the related manufacturers.	Chemist (studying conventional plastics):	You have researched plastics for over 30 years. Nowadays, people think that plastic - plastic pollution is the root of all evil, and you would like to change the public's perspectives of conventional plastics. Conventional plastics are usually more environmentally friendly and convenient than other materials, and their alternatives, such as PLA, do not perform as well as traditional plastics. Rational use of conventional plastics, recycling plastics, and avoiding leakage of conventional plastics into the environment are effective ways to solve plastic problems.
Biodegradable Plastic food container manufacturer:	You own a company that produces disposable, biodegradable plastic food containers. The disposable, biodegradable plastic food containers produced by your company were used in the Beijing 2022 Winter Olympic Games and gained a good reputation in society. It is made of PLA, which can be degraded entirely under industrial composting conditions in 3-4 months. The raw material (corn) of the product comes from renewable resources, and the product returns to nature after use, which has no pollution and no burden on the environment.	Environmental organization agent:	You are the representative of Greenpeace (China). You know that plastic pollution is a globally important issue and you are dedicated to advocating for the public to reduce plastic use. You have been concerned about plastic pollution in the food delivery industry since 2017. One of your friends sued three major online takeout platforms for plastic pollution. You found that the appropriate post-consumer treatment equipment for degradable plastics is insufficient, affecting the value of biodegradable plastics. PLA might also endanger creatures as discarded in the environment.

Supplemental material:III

The selected examples in the results of students' assignments in this teaching intervention

Students' questions in the introduction phase and one example of students' argumentation forms in the role-playing debate, are shown in Table S-3-1and Table S-3-2 below, respectively.

Table S-3-1. Students' questions about biodegradable plastics in the introduction phase

Categories		Examples	Percentage (%)
Environmental protection		Do biodegradable plastics contaminate the environment or not?	17
Scientific knowledge and application	Definition and categories	What is the meaning of biodegradable plastics? What about the categories?	8
	Raw materials, components, chemical structures	What is the main component of biodegradable plastics? What is its chemical structure?	23
	Theory of degradation, the rate of degradation	How are biodegradable plastics degraded? How long will biodegradable plastics be completely decomposed? How to increase the rate of degradation of biodegradable plastics or decrease the requirement of their degradation requirement?	34
	Performances	Are biodegradable plastics degrading during the usage stages? Are biodegradable plastics sturdier and more durable than conventional plastics?	7
Economic aspect		Is the price of biodegradable plastics higher than conventional plastics？	3
Social aspect		If people have misunderstandings of biodegradable plastics, do people more litter or not? How can biodegradable plastics be better and more rationally developed?	8

Table S-3-2. One group example of students' arguments in the role-playing debate

Role: Environmental organization agent	Position: Against	Use ban on single-use non-degradable plastic food containers in takeaway service.

Team member names:xxx, xxx, xxx, xxx, xxx, xxx

Our arguments in defense of this role: (*Provide arguments as many as possible to defend the position of the role you play, you can also explore more arguments, which can be found in scientific articles, scientific opinions, newspapers, scientifically based web pages, videos, photos, etc.*)

There are many kinds of "degradable plastics", and the definitions and standards are not clear. There are many fake-degradable plastics with "degradable" signs on the market, which will become plastic fragments after incomplete degradation and flow into the natural environment. Therefore, this series of environmental protection problems cannot be solved entirely.

Bio-degradable plastics might be as harmful as conventional plastics: To explore the impact of biodegradable plastics on the ecological environment, UNEP conducted corresponding experiments on the response of biodegradable plastics in a simulated environment. Most experimental results show that waste from biodegradable plastics is as harmful to people, biodiversity, and ecosystem functions as conventional plastics.

In land experiments, these microplastics were produced by bio-degradable plastics discorded in nature, hindered plant germination and growth, caused a reduction in annelid populations, and affected soil structure by reducing the number of large soil aggregates.

Moreover, people misunderstand biodegradable plastics, which leads to a weakened awareness of environmental protection, which may lead to aggravated environmental pollution. And the supply chain cannot keep up. Many merchants still cooperate with suppliers of conventional disposable plastic products. In terms of cost, the cost of degradable plastics is 2 to 3 times more expensive than conventional plastics. Food containers have virtually added a lot of cost to the catering industry, which means that a food container that used to cost 50 cents a piece now cost 1.5 cents. Some small businesses will not choose biodegradable plastics to save costs. (*Excerpted and revised from the original content.*)

Write down the arguments of the other roles that you can counter, as well as questions about the related role(s) on the other side:

The cost of biodegradable plastics is relatively high, so how to ensure that the seller is using biodegradable plastics?

If non-degradable plastics are banned, how to ensure that people's environmental awareness will not be weakened after using biodegradable plastics?

Since both biodegradable and non-degradable plastics are nearly harmful to the environment, why must the less costly conventional plastic be completely banned?

Paper 4

Learning about Confucian ecological ethics to promote education for sustainable development in Chinese secondary chemistry education

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Submitted to

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Learning about Confucian ecological ethics to promote education for sustainable development in Chinese secondary chemistry education

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Abstract

Incorporating cultural aspects into science education has recently been stressed in many non-western societies. However, Chinese traditional cultures are rarely discussed in Chinese science classrooms. Hence, a teaching intervention integrating Confucian ecological ethics and education for sustainable development in secondary chemistry classrooms was designed, implemented online due to the Covid-19 pandemic, and analyzed. It focuses on discussing aspects of Confucian ecological ethics in the context of a lesson plan on the socio-scientific issue of plastic use. Sixty-five 10th-grade students from an urban key public High School in Beijing voluntarily attended this research. Based on the analysis of their feedback it is suggested that Confucian ecological ethics can improve students' environmental awareness. Most students acknowledged that Confucian ecological ethics could promote Chinese sustainability-oriented chemistry education with a value-oriented approach.

Keywords: Education for sustainable development, Chemistry education, Socio-scientific issues, Confucianism, Plastic use

1. Introduction

Developments in science and technology are the base for economic and social development in industrialized and developing countries. The development raises the quality of daily life, e.g., by the availability of many new products developed by chemistry. The rapid progress of many societies in the last decades, however, also caused severe environmental challenges, such as climate change, environmental pollution, biodiversity loss, etc. To take up with these challenges, the United Nations (UN) coined the concept of sustainable development in the late 1980s, meaning that the development should meet the present generation's needs, but also concern the needs and chances of future generations (UN, 1987).

Although sustainable development has had many definitions during the previous decades, the essential meanings are similar and provide strategic frameworks for the sustainable development of the Earth (Burmeister, Rauch, & Eilks, 2012; Yang, Lam, & Wong, 2010). Three central dimensions of sustainable development were suggested: Ecological, social, and economic sustainability (UNESCO, 2005). Environmental sustainability ensures ecological integrity so that ecosystems maintain their functionality and provide the necessary evolutionary capacity to adapt to environmental changes. Social sustainability refers to realizing and maintaining social well-being and equity and includes elements such as social participation and cultural identities. Economic sustainability requires a society to utilize natural resources effectively and responsibly. The economy should be operated sustainably to obtain sustainable profits with economic growth (Khajuria et al., 2009; UNESCO, 2005; Yang et al., 2010).

In some sustainability models, culture is regarded as the fourth pillar of sustainability. Cultural action is the foundation of a sustainable society. Cultural respect and diversity can effectively promote sustainability (Hawkes, 2001; Nurse, 2007). Confucianism is one of the most influential traditional cultures in East Asia, such as in mainland China. It was founded by the Chinese philosopher, politician, and educator Confucius around 2500 years ago (Fung, 1953; Li et al., 2022). It has constantly developed to become a systemic culture and philosophy influencing Eastern Asian people's behaviors and attitudes (Feng & Newton, 2012; Li et al., 2022).

Confucian ecological ethics is a unique wisdom of seeing the natural environment. Recently, Li et al. (2022) identified the many connections between Confucianism and sustainable development concepts. Confucian ecological ethics advocates humans harmoniously living with all creatures and things in nature together. It states that humans and nature are constantly interacting and integrated into one system, which is the unity of humans and nature (*tian ren he yi*). People should benevolently treat all creatures and wisely utilize natural resources depending on nature's principles. Harmonism is the core idea of Confucian ecological ethics (Li et al., 2022). Confucian education encourages an individual to become a noble person (*Junzi*) by self-cultivation with moral practices and Confucian values which aligns Confucianism with many goals of sustainable behaviours (Li et al., 2022; Tu, 2001).

Education for sustainable development (ESD) was raised for promoting sustainable development through formal, informal, or non-formal education. ESD intends to empower current and future generations and equip them with informed decision-making ability, rational action competence and attitudes, and knowledge and skills related to the local or global implementation of sustainable development (UNCED, 1992). The UN (2015) proposed quality education as the sustainable development goal no. 4, which includes the target to ensure to provide people with knowledge and skills for sustainable lifestyles by 2030. ESD is suggested to encompass features of interdisciplinary and systems thinking, values orientation, nurturing critical thinking, problem-solving and decision-making abilities, diverse instructional methods, and local and global features (Burmeister et al., 2012; UNESCO, 2005).

Science education plays a pivotal role in forwarding ESD, not only by the teaching and learning of science but also by learning about science and its role in life and society. Scientific knowledge and technology are the groundwork for modern civilizations and highly affect current citizens' lives, society, the natural environment, and the economy (Feinstein & Kirchgasler, 2015). It is suggested that also traditional cultures are respected and highlighted in science education, at least in non-western modern societies (Ogawa, 1989). Especially, values- or wisdom-oriented approaches to science education are suggested to contribute to ESD by integrating local wisdom or cultures (e.g., Colucci-Gray et al., 2013; Zidny, Sjöström, & Eilks, 2020).

Socio-scientific issues (SSI) based science education addresses authentic and controversial societal problems (Sadler, 2004), like many sustainability challenges of today. It is considered as one of the most promising approaches for promoting science education for ESD (Burmeister et al., 2012; Juntunen & Aksela, 2014). SSI-based science education has features of authenticity, relevance, openness for discussion and evaluation, and potential for the learning of and about science (Marks &

Eilks, 2009). It means SSIs are authentic, relevant to students' life, controversial in society, and only understandable by knowledge from science and technology. SSI-based science education can be beneficial in nurturing students' cognitive development and moral cultivation to prepare future citizens and achieve scientific literacy with informed decision-making abilities and scientific understandings (Sadler, 2004; Sjöström & Eilks, 2018; Zeidler et al., 2005).

China is an industrializing country with fast growth of the economy and social development, especially during the past 40 years. However, it also faces environmental pollution and other side effects. So ESD became an important component of Chinese educational policy. As mentioned above, Li et al. (2022) depicted that Confucian ecological ethics has strong connections with sustainable development concepts and may have a promising potential for promoting Chinese science education.

In this article, an SSI-based approach for promoting Chinese chemistry education for sustainability in connection to Confucianism was chosen for curriculum design. It combines a locally relevant philosophical view and an authentic SSI. It focuses on Confucian ecological ethics and the side effects of plastic use.

2. Background

2.1 Societal and cultural aspects in chemistry education in Mainland China

Compared with the past rounds of Chinese secondary chemistry curriculum reforms, the current secondary chemistry education reform strengthened the societal dimension of chemistry education. The overall education goal is to foster young generations with excellent virtue values and abilities, such as social responsibility, innovative thinking, honesty, and practice ability (Wei, 2019).

One of the five core chemistry competencies in the 2017 version of the Chinese national secondary school chemistry curriculum standards by the Ministry of Education (MOE, 2018) is to nurture students' scientific attitude and social responsibility with sustainable development awareness of resources and environmental benignity, and abilities of decision making and public participation related to chemical issues. Furthermore, the new revision of the national secondary school chemistry curriculum standards (MOE, 2020) underscored the integration of science and culture by bringing Chinese traditional cultures into chemistry education. In the textbook guideline, the MOE (2021) pinpointed that chemistry is:

> the carrier of Chinese excellent traditional cultures should link with features of

> chemistry, select classical literature, figure stories, common sense, achievements, cultural heritages, etc., to engage students to understand embedded ideas and methods, reflect Chinese wisdom and creativity, foster students with spirits of bravely investigating and self-cultivation, insisting on cultural confidence and enhance cultural pride. (p. 8)

Yang, Chi, and Wang (2022), however, analyzed 76 Chinese chemistry classes and found that only a few of them were related to Chinese traditional cultures and at a superficial level. The classes lacked a sound understanding of Chinese traditional cultures. The teachers neglected the meaningfulness of Chinese traditional cultures for nurturing students' abilities of analysis and application and value influences. Other studies (Li & Eilks, 2021; Li et al., 2022) also indicated that science education for sustainability including cultural perspectives is still neglected in China.

2.2 The societal and scientific aspects of plastic takeout food containers use in Mainland China

The Chinese government raised growing attention to deeply promoting sustainable development since the 2010s by recognizing the economic, social, cultural, and political aspects of environmental protection (Gu et al., 2020). Plastic pollution, single-use plastics in particular (Geyer, Jambeck, & Law, 2017), is a big global issue, but also in China. China has issued plastic use policies since the late 2000s. The policies respond, among others, to the growing use of single-use plastics in takeaway services, accompanied by the rapid growth of food delivery industries during the last decade (Liu et al., 2022). It became the young adults' lifestyle with its convenience and brought more employment opportunities with tremendous economic value. Only in 2020 did takeout food services produce 1.6 million tons of plastic waste in China. The waste was mainly from single-use plastic food containers, rarely recycled with low economic value, and contaminated by oil and water (Zhang & Wen, 2022).

The Covid-19 pandemic aggravated the consumption of plastic containers for takeout food in China even more. For instance, in one of the three leading Chinese takeout food platforms, *Meituan*, the daily takeout food orders surpassed 60 million in 2022 (Xinhuanet, 2023). This development raised a hot public debate about if conventional single-use plastic food containers should be banned in China. In early 2020, the National Development and Reform Commission and the Ministry of Ecology and Environment of China (2020) started releasing related policies prohibiting and restricting plastic use and production in takeaway food industries. Conventional disposable plastic bags and straws were banned. By the end of 2025, plastics cutlery in takeout services should be reduced by 30% in Chinese cities, and alternative biodegradable plastics are recommended.

Polypropylene (PP) is the most used conventional plastic for food containers in the Chinese takeout food industry (Zhang & Wen, 2022). PP has excellent strength and mechanical properties, heat and chemical resistance, low density, high safety, good moisture or air barrier performance, etc. It is also very cheap and widely used in various areas compared to other materials (Allahvaisi, 2012). Otherwise, PP is non-biodegradable and made of non-renewable resources. Mismanaged end-of-life PP has the potential to threaten creatures.

On the other hand, Polylactic acid (PLA) is one polyester made from renewable resources, such as corn starch. It has good biocompatibility, biodegradability, and mechanical and strength properties. Hence, it is widely used in many packaging industries, considered as one of the most promising alternatives to conventional plastics, such as for takeout food containers (Zhao et al., 2022). However, it is very brittle and has low heat resistance. There are many misunderstandings related to the biodegradability of PLA. The disposal of it should be under certain industrial composting conditions to be completely decomposed. In other words, if PLA were disposed of in the natural environment, it would also cause environmental pollution (McKeown & Jones, 2020). There is not yet any suitable treatment equipment for PLA waste in most Chinese cities. This fact challenges the public's arguments about whether or not to ban conventional plastic single-use takeout food containers and replace it with PLA.

3. Research aims and questions:

This study focuses on Confucian ecological ethics in Chinese secondary chemistry education and digs into students' perceptions. The teaching intervention was inspired by Park, Erduran, and Guilfoyle (2022) and de Waard, Prins, & van Joolingen (2020). It is to nurture students' sustainability-related abilities, such as communication and argumentation abilities, environmental-friendly attitudes, decision-making abilities, and competence of social responsibility (Wiek, Withycombe, & Redman, 2011).

The research questions are:

1. What are students' perceptions of a teaching intervention about integrating Confucian ecological ethics into SSI-based chemistry education for ESD?

2. What are students' views of the potential role of Confucian ecological ethics in secondary chemistry education in China?

4. The lesson plan design and implementation

Lee, Lee, and Zeidler (2020) elucidated that teachers should pay attention to the following aspects of SSI-based science instruction in East Asian countries: The lesson should be built as a cooperative environment, showing the reasons for discussion, and presenting uncertainty in the application of science. In this case, the learning design used the tandem cooperative learning method, in which individuals finish tasks first, discuss the results with their partners to achieve common or similar solutions, and then display their views to the whole class. The instructor mainly facilitates students' learning by introducing the topic, raising questions, observing, guiding, offering help, and assessing students' learning. Due to the Covid-19 pandemic policy in China, this course was designed as online teaching, and related media was used, such as Tencent meeting, Tencent Docs, and Padlet.

The teaching intervention consists of three parts: the introduction, the understanding of Confucian ecological ethics in connection to sustainability thinking, and the application of Confucianism and sustainability thinking within an SSI on the plastic used for takeout food containers (Table 1). The intervention lasted 135 min.

The introduction phase started with a short edited video on plastic pollution (the original video with Chinese subtitles is found at https://www.youtube.com/watch?v=1_HBgvmrhGU&t=4s). A question of what actions we should take for the future of the Earth was followed. It was to provoke the view on sustainable development and Confucian ecological ethics. Furthermore, teaching content, method, goals, and assessment were introduced.

In the second phase, two short articles about Confucian ecological ethics and sustainable development concepts were provided. The texts were compiled from Chinese mainstream public media and academic articles. Both texts were modified to be comprehensible for high school students. The compiled versions were checked by an experienced high school chemistry teacher and a science education expert. The article on Confucian ecological ethics consists of core ideas, such as the unity of humans and nature, harmonism, benevolence, rationally using natural resources relying on time and natural patterns, modern perspectives of Confucian ecological ethics, etc. The sustainable development article contains the three core ideas of sustainable development, ecological benignity, social equity, and economic feasibility, including their relationship. Every two students formed a tandem. One student firstly marked the key sentences in one article, e.g., in Tencent docs, concluded the main ideas, prepared a short presentation, and shared it with his or her partner. After that, the second student presented her or his work on the other article. Students were asked to discuss and compare the two texts. The two students were asked to further discuss the differences and similarities between Confucian ecological ethics and sustainable development concepts and create a Venn diagram (Park et al., 2022) to show the relationships. Finally, all tandems shared their diagrams with the whole class, and other students were asked for comments.

Students were required to write one public service advertisement advocating sustainable development and Confucian ecological ethics (within 40 Chinese characters). This was to apply students' understanding of sustainable development and Confucian ecological ethics and build their connection between themself and society, based on the modern explanation of the Confucian unity of humans and nature (Tu, 2001). One public service advertisement, "*the conservation of biological diversity and the establishment of ecological civilization together*" (https://www.bilibili.com/video/BV1Yv41177B5/?vd_source=775c8fbc673aab242a5935ce69d1f5c4) was provided, as an example. Students showed their solutions, and others evaluated with thumbs-ups or provided comments on a Padlet.

To inspire students to think more deeply about Confucianism in the context of chemistry education for ESD, a further question was raised: "*Do you think Chinese high school chemistry textbooks should properly add any Confucian ecological ethics*? " This question was addressed since the latest Chinese high school chemistry textbooks mentioned sustainable development rather than Confucian ecological ethics (People's Education Press, Curriculum and Textbook Institute, & Chemistry Curriculum and Textbook Research and Development Center, 2019). Students were instructed to discuss in groups and present their positions and arguments to the class on a Padlet. All students were asked to comment on the given arguments. They further discussed their views in a plenary meeting.

In the final phase, data on the plastic used in takeaway food services was presented. The presentation was followed by the authentic context in public consultations on plastics used in takeout food services from China's National Development and Reform Commission: "*The Announcement on inquiring public opinions on the draft of the catalog of prohibited and restricted plastic products in production, sale and use*" (https://hd.ndrc.gov.cn/yjzx/yjzx_add.jsp?SiteId=332). The discussion centered around the question: *Should conventional disposable plastic takeout food containers be added to the Catalog of Plastic Products Prohibited and Restricted in Production, Sale, and Use in China?* The conventional and alternative plastic takeout food containers mostly discussed are based on PP and PLA, respectively. PLA and PP were briefly introduced with information, such as chemical structures, manufacturing processes, biodegradability, etc. The chemical structures of PP and PLA were displayed for students' discussion of the differences. This introduction was done by a short edited video with Chinese subtitles to provide scientific expertise for the issue (The original video link, https://www.youtube.com/watch?v=-_eGOyAiNIQ&list=PLHI39OgEVkP38JuvQZReGFRL0Fbe8iwZ-&index=20&t=290s).

Students formed small groups to discuss and suppose positions and views from the perspective of Confucian ecological ethics on banning conventional disposable plastic takeout food containers or not. The core opinions and arguments about this issue from society were presented in information cards. One critical review essay (500-800 words) was to be written by the groups as their homework assignment. The essay had to be related to the students' positions and viewpoints or arguments on the issue of the ban use of conventional disposable plastic takeout food containers, concerning the public perspectives, sustainable development, Confucian ecological ethics, and scientific knowledge. They also had to prepare 60 seconds short presentation to the class about the main idea of their essay, and the others were asked to assess them. Finally, by presenting, assessing, and discussing the presentations, students had a chance to further understand the complexity of dealing with an SSI in the foreground of Confucian ecological ethics and sustainability thinking.

Table 1. The structure of the teaching intervention about understanding Confucian ecological ethics in depth in Chinese secondary chemistry education

Phase	Content	Purpose	Media and learning
Introduction (10 min)	● One edited short video about plastic pollution. ● The introduction of sustainable development and Confucian ecological ethics. ● The description of the structure and contents of the course, and learning tasks, method, and evaluation.	● To prepare students to learn and take them into the topic. ● To draw students' interest in learning and know the goal of the lesson.	Video, presentation, Plenary meeting, Tencent meeting, listening and thinking
Learning about Confucianism	● The core ideas of Confucian ecological ethics and sustainable development from two short articles. ● The comparison of differences and similarities between	● To learn the core ideas of sustainability and Confucianism, and compare their similarities and differences.	Articles, video, Tencent docs, presentation, Padlet,

and Sustainable development (70 min)	Confucian ecological ethics and the ideas of sustainable development in one Venn diagram. ● Writing a public service advertisement for "Sustainability and Confucianism." ● The discussion of one question "*Do you think Chinese high school chemistry textbooks should properly add any Confucian ecological ethics*?"	● To further understand sustainability and Confucianism, and the role of Confucianism in Chinese secondary chemistry education for ESD. ● To nurture students' communication skills, normative competency, argumentation, innovation and evaluation abilities, and social responsibility.	Tencent meeting, Plenary meeting, Tandem mode (or 1-2-all mode) cooperative learning.
Application related to one daily issue of plastic takeout food containers (40min)	● Disposable plastic takeaway food containers use issue with one consultation announcement and brief data in China ● A short video of a brief introduction of PP and PLA chemical knowledge, and biodegradable plastics. The analysis of the differences of PP and PLA, e.g., in chemical structures. ● Writing a critical news article about their position and arguments about the ban on plastics used in takeaway food containers concerning the social, cultural, and chemical aspects and ESD, and presenting the core idea about the article to the class with 1min. ● Presenting presentations, evaluating them, giving related comments, and discussing with the class.	● To bring the controversial issue of ban of plastics used in takeout food containers ● To know the chemical knowledge related to this issue ● To understand Confucian ecological ethics, sustainable development, society, and chemical knowledge by making decisions on the SSI. ● To nurture students' argumentation ability, macro-identification and micro-analysis competency, action competence, decision-making ability, and evaluation skills.	Videos, Information cards, Tencent Docs, Padlet, Tencent meeting, Plenary meeting, 1-2-all mode cooperative learning.
Reflection (15min)	● A feedback questionnaire about students' interest in this course, students' perspectives on Confucianism in Chemistry education for ESD, relevance to the chemistry curriculum, and students' learning results.	● To reflect and assess their learning and perceptions of the lesson plan.	Wenjuanxing (*online questionnaire platform*)

5. Sample and method

The lesson plan was implemented online due to the Covid-19 pandemic policy in January 2023. It was operated at an urban public high school in Beijing (China) where students have high levels of studying achievements. Before the class, the chemistry teacher briefly introduced this lesson and the including teaching goals.

Sixty-five students (26 males and 39 females from four 10^{th}-grade classes, age range 15-16) voluntarily signed up to take the lesson. The chemistry teacher assigned every two students one studying group, allowing them to change their groups ahead of the class slightly. The students had learned chemical bonding and organic chemistry at the preliminary level. The first author taught the intervention. The students attended and finished the course, and then filled the feedback questionnaires. The chemistry teacher was an assistant and observer to observe students' learning and offer help as students needed, and filled in one observation form about students' learning and the teaching methods.

After the lesson, the whole class reflected on the course with a feedback questionnaire with three open-ended and twelve Likert scale questions (4-step). The questionnaire evaluated students' experiences and perceptions of the lesson, such as their interest in learning, teaching method, relevance to the curriculum, and their views on incorporating Confucianism into chemistry education.

Finally, 63 students filled out the questionnaire. The open-ended questions and Likert questions in the students' feedback questionnaires were evaluated by qualitative content analysis according to Mayring (2014) and descriptive statistics, respectively. For the qualitative analysis, two raters took two rounds of analyzing students' answers to the open-ended questions. In the first round, the two raters independently analyzed the data and inductively formulated categories and themes with an agreement percentage rate of 85%. The disagreed or unclear parts were further discussed to reach an agreement. In the second round, the two raters further analyzed the data to achieve a category system to show the students' answers to open-ended questions in the questionnaire. The final inter-rater reliability was very good with Cohen's kappa value of $\kappa = 0.876$. Students' assignments and the teacher's observations were also used to interpret the feedback and teaching results.

6. Findings and discussion

The students' answers to the Likert items are shown in Figure 1. Most students enjoyed learning this topic with high interest and appreciated the teaching pedagogy. The student perceived to have gained certain learning abilities, including increasing environmentally friendly awareness and social responsibility. Most students (with answers of nearly 90% strongly agreed, agreed, or partially agreed) were interested in this topic of lessons and motivated to learn chemistry in Items 1 and 3. The learners liked the instructing and learning methods (nearly 80% strongly agreed or agreed, and only 2% disagreed with Item 2). They also felt trained with cooperative learning and communication (63% disagreed with item 4). These were in parallel with answers to the open-ended question: *What is your satisfaction with the lesson (with a scale of 0-5, from low to high), and what are the good parts or the parts to be improved?*

Figure 1. The results of students' Likert items in the feedback questionnaire (N=63).

On average, students gave 4.3 out of 5 on the satisfaction scale, and 82% thought the course was 4 or 5. Fifty students pinpointed that the lessons were designed well and innovatively (32) or the content was significant (18). Fourteen students hoped that more case studies or more detailed information about Confucianism and sustainability would be provided or the online learning platform could be improved. For instance, the followings were some quotations from the students' answers. "*Although it was implemented online, cooperative learning of connecting chemical knowledge and environmental issues, and integrating hot, social issues [with Confucianism] were worthwhile in this lesson topic. I hope this activity can have a constant influence on future activities.* " "*The learning plan, interaction, and learning tasks were very impressive; no more improvement was needed.*" "*The questions raised were very interesting; the topic was relevant to our daily life and innovative.*" "*The content was very valuable, and it connected the two [sustainable development and Confucian* *ecological ethics] that were seemingly unrelated...*" The chemistry teacher also said most students actively participated in class, and they were accredited to the teaching method regarding students' classroom behaviors and expressions.

The lesson plan also seemed to have improved students' perceptions of chemistry and the related areas. Most of the students (92% strongly agreed or agreed with Item 5) considered that chemistry classes need to encompass issues of society, environment, economy, and culture. It also made most of them feel they understood the complexities of chemical issues (93% strongly agreed, agreed, or partially agreed in Item 7). Eighty-two percent agreed this topic was relevant to them (Item 6). Their viewpoints about adding Confucian ecological ethics into the high school curriculum were as follows: 65% agreed, and 14% disagreed (Item 9). These were similar to their arguments in one assignment in the class: *Should Confucian ecological ethics be included in Chinese high school chemistry textbooks*? Thirty-nine agreed; otherwise, 26 disagreed. The students who agreed stated that Confucian ecological ethics could assist in understanding sustainable development. They also mentioned that localization at the global age is essential, integrating science and culture with benevolence or valued orientation is urgent for future citizens, etc. However, some students who disagreed commented that Confucian ecological ethics is not science without strict experiments and data. They saw it as already included in sustainability thinking. In general, most students acknowledged the potentially positive role of Confucian ecological ethics in sustainability-oriented chemistry education in China.

Lastly, most students approved that Confucian ecological ethics can benefit their understanding of sustainable development, provide local wisdom to global issues, and facilitate achieving sustainable chemistry (94% strongly agree, agree, or partially agree in Items 8, 10, and 11). Their environmental awareness and social responsibility with future actions were enhanced by this topic (81% strongly agreed or agreed, and 6% disagreed with Item 12). This is visible in one group's writing a public service advertisement: "*Harmonism will create new things, achieving sustainable development; sameness will not, facilitating the biological prosperity*." This quote matches students' answers to the open-ended question: *What is the most important content you have learned from this topic of lessons*? Forty-seven students (75%) thought they had learned the relationship between Confucian ecological ethics and sustainable development, and both concepts have many perspectives in common. Twenty-six students (41%) also reflected that Confucian ecological ethics plays a vital role in environmental protection and can be beneficial to reach chemistry education for ESD in China. For example, one student said: "*I studied the most important content was Confucian ecological ethics connecting with chemistry, and its application in our life, providing a basis to understand sustainable development*." One of the students wrote, "*I learned Confucian ecologic ethics also has a tight connection with the modern environmental protection idea, sustainable development.*" Another student stated: "*Culture also can have a subjective effect on science."* The chemistry teacher also insisted that deeply understanding Confucian ecological ethics could assist in fostering students' environmentally-friendly attitudes and behaviors.

Furthermore, students pointed out the active role of Confucian ecological ethics in chemistry education in the related open-ended question, where they were asked to write the 1-2 core viewpoints about the role of Confucian ecological ethics in Chinese chemistry education. Thirty-seven students claimed Confucian ecological ethics could connect science and culture to form Chinese sustainable chemistry research with values or moral orientation; 30 students considered that it could attach to environmental issues and enhance people's environmental-friendly awareness, social responsibility, and actions; and 27 students expressed that it can be closer to our daily life, and increase students' learning interest, and cultural confidence.

The answers from the students imply that they agreed on the moral function of Confucian ecological ethics in chemistry education for sustainability. Confucian ecological ethics can foster social responsibility and motivate students to learn chemistry. For instance, one student wrote, *"Researchers should rationally use natural resources as doing chemical innovation, and propose and research better products to replace non-recyclable products."* Another student wrote: "*Confucian unity of humans and nature stresses the harmonism of humans and nature. However, learning chemistry is to know and utilize chemistry knowledge and take social responsibility. Confucianism as Eastern wisdom has special understandings of sustainable development, and connects with the content of sustainable development from chemistry textbooks, which can make students deeply understand sustainable development*." Another student added: "*I think that Chinese traditional culture connecting with chemistry education is a very creative starting point, which also reflects our cultural pride at the same time. Additionally, it can smoothly bring our daily examples, make us more interested in the topic and learn more.*" One student also mentioned that some chemical reactions were presented in Confucianism, i.e., such as clothes dying in *the Analects*, or chemical reactions described by Confucianist Ge Hong. "*So things may gain when they seem to lose,* *or lose when they seem to gain*" (Xu, 2011). It is similar to chemical equilibrium shifted by changing the amount of products or reactants.

All in all, this teaching intervention is in accordance with Li's (2022) findings that Chinese secondary chemistry education fusing the traditional culture with a topic of carbon could enhance students' cultural confidence and moral cultivation. Li (2022) used classical phrases about the rational utilization of natural resources to show ancient Chinese environmental friendliness ideas. He also pointed out that the collected materials related to Chinese traditional culture should have logical connections with specific chemistry knowledge, such as archaeological discoveries and classical literature. It is also following Peng and Zhang (2022) who pinpointed that chemistry education merged with traditional cultures can motivate students' learning, open their minds, and shape their values and worldviews by learning chemical knowledge of sulfur from Chinese classics books in a historical view. These teaching interventions showcased the sound potential of integrating local wisdom and cultures with science education, like it was also reported for incorporating indigenous minority science knowledge in science education (Zidny & Eilks, 2020). Comparing with Li, Ding, and Eilks, I (under review), the authors found that more students were engaged in learning and recognized the potential role of Confucianism in chemistry education for ESD in this research by stronger focusing the philosophical context for students' deep understanding of Confucianism and sustainable development.

7. Conclusion

Incorporating Confucian ecological ethics into chemistry education is quite new to Chinese high school students. According to the students' feedback and assignments, the authors can find that this lesson plan catalyzed their values or worldview changes with positive results on their environmental awareness. It triggered new ways of thinking, such as being more open-minded towards science and humanism. Hence, this philosophical context provided chances for multiple perspectives for students' solving SSIs (Broggy, O'Reilly, & Erduran, 2017; Park et al., 2022). Students' thinking and discussion also benefited the teacher. For instance, one group of students proposed the differences and similarities between Confucian ecological ethics and sustainable development in Figure 2. They thought sustainable development has a more powerful execution than Confucian ecological ethics, and the latter is more gentle with benevolence. The former is societal-centered, and the latter focuses on individual cultivation with the features of Confucian education, such as being a noble person (*Junzi*). This also might be a difference between Western modern and Eastern cultural views (Li et al., 2022), and elaborating on this difference was also new for the teacher.

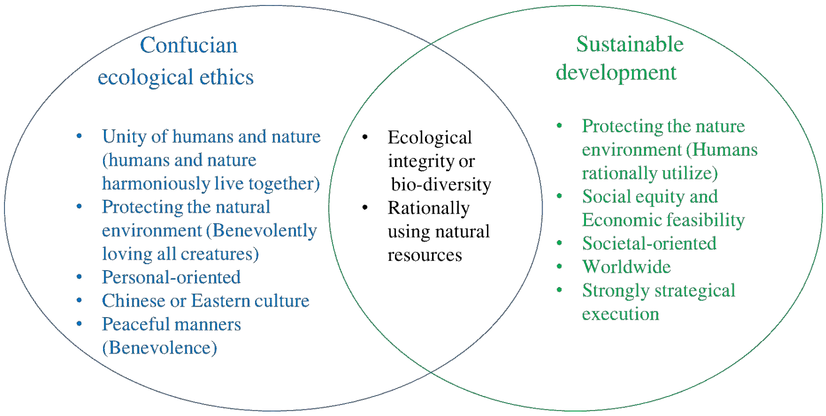

Figure 2. *One student group's solution example of similarities and differences between Confucian ecological ethics and sustainable development in a Venn diagram.*

The implementation showed the sound potential role of Confucian ecological ethics in Chinese ESD-oriented chemistry education, from students' positions. It can contribute to enhancing scientific literacy from an angle of the cultural aspect. However, this is a long way to go. Some students thought science and culture should be separated. It was in line with Zhang and Liu's (2021) conclusion based on one societal debate of humanism and science in the late 2010s in mainland China. They suggested that the enhancement of the nature of science should be emergent. The chemistry teacher in this case, also suggested that future studies should look for topics with positive figures of China, and some ideas of Chinese traditional cultures can be used worldwide. However, students' interest in learning and confidence in the traditional culture was present in this research. In-service chemistry teachers might play an essential role in promoting culture-oriented and SSI-based science education in China. Even though the new Chinese high school chemistry curriculum standards highlighted fusing traditional cultures in chemistry classrooms, it might urgently need to train chemistry teachers with more cultural awareness and effective strategies.

This study has some limitations. The lesson was online tested only with a limited number of students with only three periods of chemistry classes in one school; students' learning achievements and class sizes might not be the most representative, for China has a vast territory and school contexts might have quite differences from the east to the west. More case studies about integrating science and culture will be needed with more students to fully exploit the potential of incorporating non-Western philosophical views into science education to prepare learners for a sustainable future in a diverse world.

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Author contributions

All authors have accepted responsibility for the entire content of this manuscript and approved its submission.

Competing interests

The authors state no conflict of interest.

Informed consent

Not applicable.

Ethical approval

This research got the permission of the academic dean and the student management dean of the school to take responsibility for communicating with students' parents.

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