THE EFFECTIVENESS OF STrEaM-AR-CC IN REDUCING MISCONCEPTIONS ON CLIMATE CHANGE, IMPROVING SYSTEMS THINKING SKILLS AND RELEVANCE AMONG FORM TWO STUDENTS

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by

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
ACE	Action for Climate Empowerment
AR	Acid Rain
AR	Augmented Reality
AREPDiT	Atmosphere-Related Environmental Problem Diagnostic Test
CC	Climate Change
CFC	Chlorofluorocarbon
GE	Greenhouse Effect
GHG	Greenhouse Gaseous
GW	Global Warming
IPCC	Intergovernmental Panel on Climate Change
MOE	Ministry of Education
OLD	Ozone layer depletion
STEAM	Science, Technology, Engineering, Arts and Mathematics
STEM	Science, Technology, Engineering and Mathematics
STH	Systems Thinking Hierarchical
STrEaM	Science, Technology, reading and writing, Engineering, arts and Mathematics
UNFCCC	United Nations Framework Convention on Climate Change
ROSE	Relevance of Science Education
SDG	Sustainable Developmental Goal

LIST OF APPENDICES

KEBERKESANAN STrEaM-AR-CC DALAM MENGURANGKAN MISKONSEPSI TERHADAP PERUBAHAN IKLIM, MENAMBAH BAIK KEMAHIRAN SISTEM BERFIKIR, DAN KERELEVANAN DALAM KALANGAN PELAJAR TINGKATAN DUA

ABSTRAK

Perubahan iklim merupakan isu kompleks yang telah menarik perhatian kerajaan dan masyarakat; serta menjadi kegusaran besar dalam pendidikan di Malaysia. Pedagogi perubahan iklim yang distruktur dengan baik dan relevan dapat membantu pelajar memahami pengetahuan sains iklim, menggambarkan konsep abstrak dan membangunkan keupayaan masa hadapan dalam menyelesaikan permasalahan perubahan iklim. Rekabentuk intervensi menggunakan kaedah gabungan ini bertujuan membangunkan pedagogi perubahan iklim yang berkesan berdasarkan amalan semasa. Peringkat pertama kajian meneroka amalan semasa dalam pengajaran dan pembelajaran perubahan iklim bagi topik ekosistem dalam kalangan guru dan pelajar tingkatan dua. Penemuan kualitatif penerokaan ini menjadi asas pembentukan pedagogi perubahan iklim dalam peringkat kedua. Amalgamasi STrEaM (Sains, Teknologi, pembacaan dan penulisan, Kejuruteraan, seni dan Matematik) dan aplikasi mobil AR (realiti terimbuh) membuka laluan kepada pendekatan pengajaran dan pembelajaran STrEaM-AR-CC. Dalam peringkat ketiga, pengukuran dibuat bagi mengkaji keberkesanan STrEaM-AR-CC terhadap miskonsepsi, kemahiran sistem berfikir dan persepsi kerelevanan perubahan iklim sebagai pendidikan sains dalam kalangan pelajar tingkatan dua. Reka bentuk penyelidikan kuasi, kumpulan kawalan sebelum dan selepas tak setara dilaksanakan. Sampel berjumlah 122 pelajar Tingkatan Dua dari dua sekolah menengah di Pulau Pinang dikelaskan secara rawak sebagai

kumpulan kawalan dan eksperimen. Temubual dijalankan ke atas pelajar dalam kumpulan eksperimen sebelum dan selepas pelaksanaan STrEaM-AR-CC bagi menyokong penemuan data kuantitatif. Dapatan kualitatif menunjukkan miskonsepsi terhadap perubahan iklim dalam kalangan pelajar berkurang manakala kemahiran sistem berfikir dan persepsi berkaitan kerelevanan pendidikan sains dalam kalangan pelajar selepas pelaksanaan STrEaM-AR-CC meningkat. Dengan menggunakan Ujian Diagnostik Berkaitan Alam Sekitar (AREPDiT) bagi mengukur miskonsepsi pelajar terhadap perubahan iklim, MANOVA menunjukkan perbezaan yang signifikan secara berstatistik antara kumpulan eksperimen dan kawalan bagi gabungan konstruk miskonsepsi, $F (4,119) = 67.766$, $p<0.05$; Wilk's $\Lambda = 0.305$; separa $\eta^2 = 0.695$. Kemahiran sistem berfikir pelajar diukur menggunakan instrumen Sistem Iklim dengan MANOVA menunjukkan perbezaan signifikan secara berstatistik antara kumpulan eksperimen dan kawalan bagi gabungan aras kemahiran sistem berfikir, $F (2,121) = 457.020$, $p <0.05$; Wilk's $\Lambda = 0.117$; separa $\eta^2 = 0.883$. Persepsi pelajar berkaitan kerelevanan pendidikan sains diukur menggunakan soal selidik ROSE yang diubahsuai, dengan MANOVA menunjukkan perbezaan signifikan secara berstatistik antara kumpulan eksperimen dan kawalan dari segi persepsi terhadap kerelevanan pendidikan sains, $F (3,120) = 411.733$, $p<0.05$; Wilk's $\Lambda = 0.089$; separa $\eta^2 = 0.911$. Secara kolektif, pendekatan pengajaran dan pembelajaran STrEaM-AR-CC mengurangkan miskonsepsi terhadap perubahan iklim serta menambahbaik kemahiran sistem berfikir dan persepsi terhadap kerelevanan pendidikan sains dalam kalangan pelajar.

THE EFFECTIVENESS OF STrEaM-AR-CC IN REDUCING MISCONCEPTIONS OF CLIMATE CHANGE, IMPROVING SYSTEMS THINKING SKILLS, AND RELEVANCE AMONG FORM TWO STUDENTS

ABSTRACT

Climate change is a complex issue that has drawn significant attention from the government and society; and is a paramount educational concern in Malaysia. A well-structured and relevant climate change instruction can facilitate students' ability to comprehend the knowledge of climate science, visualize the abstract concept and develop future capabilities to solve climate change problems. This interventional mixed-method study was aimed at developing an effective climate change instruction based on current practices. The first stage of the study explored the current practices of teaching and learning climate change in the ecosystem topic among secondary school students and teachers. The qualitative findings of the exploration informed the development of climate change instruction in stage two. The amalgamation of Science, Technology, reading and writing, Engineering, arts, and Mathematics (STrEaM) and AR (augmented reality) mobile application give rise to STrEaM-AR-CC teaching and learning approach. In the third stage, the effectiveness of STrEaM-AR-CC on the misconceptions of climate change, systems thinking skills and the relevance of science education among form two students were measured. A quasi-experimental, non-equivalent, pre- and post-test control group design was executed. A sample of 122 Form Two students from two secondary schools in Penang was randomly assigned as control and experimental groups. Interviews were conducted on the students from the experimental group before and after the execution of the STrEaM-AR-CC to gauge insight into the quantitative findings. The qualitative findings revealed that students' misconceptions of climate change were reduced, students' systems thinking skills and their perception on the relevance of science education have been improved after the implementation of STrEaM-AR-CC. Using the Atmosphere-Related Environmental Problem Diagnostic Test (AREPDiT) to measure students' misconceptions on climate change, MANOVA showed a statistically significant difference between the experimental and control group on the combined misconceptions constructs, F (4,119) = 67.766, $p<0.05$; Wilk's $\Lambda = 0.305$; partial $\eta^2 = 0.695$. Students' systems thinking skills was measured using the Climate Systems instrument and MANOVA indicated a statistically significant difference between the experimental and control group on the combined systems thinking skills levels, F (2,121) = 457.020, $p<0.05$; Wilk's $\Lambda = 0.117$; partial $\eta^2 = 0.883$. Students' perception on the relevance of science education was measured using adapted ROSE questionnaire where MANOVA revealed a statistically significant difference between the experimental and control group for perception on the relevance of science education, F (3,120) = 411.733, p <0.05; Wilk's $\Lambda = 0.089$; partial $\eta^2 = 0.911$. Collectively, STrEaM-AR-CC teaching and learning approach reduced misconceptions about climate change, improved systems thinking skills and perceptions of the relevance of science education among students.

CHAPTER 1

INTRODUCTION

1.1 Introduction

The Ministry of Education has identified eleven shifts in Malaysia Education Blueprint 2013-2025 (PPPM) to raise Malaysian education standards in preparing children to meet the needs of the 21st century. Shift one states providing equal access to quality education of an international standard. One of the benchmarks in shift one is strengthening the quality of Science, Technology, Engineering, and Mathematics (STEM) education across primary and secondary schools to produce quality and sufficient human capital in STEM that would drive the economy (Ministry of Education Malaysia (MOE), 2013). STEM education in Malaysia aims to produce STEM-literate students who can identify and understand problems, as well as apply and integrate STEM concepts into appropriate solutions. In 2017, Form 1 students in Malaysia's secondary school curriculum, known as Kurikulum Standard Sekolah Menengah (KSSM), began incorporating STEM integrated education (Bahrum et al., 2017).

STEM education was introduced as an interdisciplinary approach to teaching and learning that eliminates the traditional barriers separating the four STEM disciplines and integrates them into real-world, rigorous, and relevant learning experiences for students in the classroom (Vasquez et al., 2013). STEM education has limitations, whereby teachers lack skills and knowledge in interdisciplinary teaching (Ismail et al., 2019; Kelley & Knowles, 2016). Several initiatives have been undertaken to overcome the notion that teachers are enduring challenges in performing interdisciplinary teaching (Karpudewan et al., 2022; Subramaniam et al., 2022).

However, the challenges remain (Ismail et al., 2019). One possible way for implementing interdisciplinary teaching is through integrating reading, writing, and arts components within STEM disciplines which results in STrEaM. Research on the STrEaM approach is still in its infancy. Reading and writing are integral to teaching and learning science because, according to Osborne (2010), reading and writing enable students to communicate their ideas to the public about what they have comprehended through teaching and learning in the classroom. Reading and writing components represented activities carried out during teaching and learning. Reading and writing are components for crossing the discipline of STEM. The arts component refers to drawings, diagrams, graphs, and tables used in the lesson throughout the teaching and learning activities. Arts components also allow crossing the disciplinary of STEM. Integrating reading, writing, and art components into STEM disciplines and embedding them as STrEaM is an interdisciplinary teaching and learning approach (Subramaniam et al., 2022).

In Malaysia, global climate change is a significant complex issue that has drawn attention from society and the government (Karpudewan & Mohd Ali Khan, 2017), and it is a paramount educational concern. The issue of climate change is a global threat that has begun to stress many sectors, such as the agricultural and global tourism industries (Abbass et al., 2022). The climate change phenomenon is a real-world problem affecting humans in various areas of their lives (IPCC, 2021). This is because Malaysia is experiencing climate change impacts, such as frequent floods, drought, rising sea levels, and temperatures (Alam et al., 2011; Tang, 2019). In order to educate students about the phenomena of climate change, which is interdisciplinary in nature, the STrEaM teaching and learning approach involves learning basic science concepts in a transdisciplinary manner (Vasquez et al., 2013), which is deemed relevant and appropriate. This is because the conceptualisation of climate change cannot be rationalised through a single dimension; rather, the climate is a complex system that is connected with various disciplines. Integrating STrEaM disciplines into the teaching of climate change provides clear multiple perspectives on climate change.

In addition to its transdisciplinary nature, the pedagogical strategy for learning climate change should embark students to visualise climate change phenomena in real-world. Augmented Reality (AR), which is one of the nine pillars of the 4^{th} Industrial Revolution (4IR), is a technological tool that displays three-dimensional (3D) representations of phenomena (Roy et al., 2017). When used as a platform to present climate change phenomena such as the greenhouse effect, AR prompts students to interactively experience the 3D visualisation of the effect (Cabiria, 2012). Following the development of context-aware technologies such as mobile phones and tablets, AR has become more robust in becoming an outstanding technology (Dunleavy & Dede, 2014b; Roy et al., 2017). The amalgamation of STrEaM –and AR mobile application to present climate change as a multiple-perspective real-world phenomenon in a three-dimensional view give rise to a teaching and learning approach known as STrEaM-AR-CC. The STrEaM-AR-CC approach facilitates the conceptualisation of climate change in the ecosystems topic among secondary school students, as the climate is a complex system that cannot be rationalised through a single dimension.

Since STrEaM-AR-CC allows viewing climate change phenomena in three-dimensional presentation and learning the issues in a transdisciplinary, STrEaM-AR-CC possibly reduces misconceptions about climate change among secondary school students. Systems thinking is integral to science teaching and learning (Ratinen, 2013). Mainly, systems thinking is necessary for a comprehensive understanding of complex systems such as climate change (Roychoudhury et al., 2017). System thinking influences students' ability to comprehend components and processes in the climate system. A solid grasp of systems thinking facilitates making more informed decisions in the near future (Arnold & Wade, 2015), especially in reducing the anthropogenic causes of climate change. STrEaM-AR-CC allows teaching and learning about the climate system as a whole to promote students' understanding of the interconnectedness of climate system components. Hence, STrEaM-AR-CC is a viable teaching and learning approach to inculcate system-thinking skills among secondary school students in the context of teaching and learning about climate change.

In the context of science education, relevance is characterised whenever science learning has positive consequences for the student's life that encompasses fulfilling actual needs related to students' interests or educational demands and anticipating future needs (Stuckey et al., 2013). Science education's relevance can be viewed from individual, societal and vocational dimensions (Stuckey et al., 2013). Climate change is considered a relevant socio-scientific issue (Feierabend & Eilks, 2010; Sadler, 2011) that is appropriate to be taught to secondary school students because any societal decision on climate change directly impacts the lives of the students, either now or in the future (Marks & Eilks, 2009). Hence, students would be able to perceive the relevance of learning about climate change from the individual, societal and vocational dimensions (Stuckey et al., 2013).

Therefore, through this study attempt was made to develop STrEaM-AR-CC as a teaching and learning approach to be used during Form Two science lessons on climate change integrated within the topic of Ecosystem to reduce students' misconceptions on climate change, improve systems thinking skills and perceptions on the relevance of the science education.

1.2 Background of the Study

Climate Change Synthesis Report indicates that human influence on the climate system is continuously growing (IPCC, 2014). According to the most recent report published by Intergovernmental Panel on Climate Change (2021) dictates that human action is the primary cause of the destruction of the climate. In Malaysia, global climate change has become a significant issue for society and the government (Karpudewan & Mohd Ali Khan, 2017). Climate change in Malaysia is a reality reflected via the historical climate data, particularly of mean daily temperature, mean sea level and records of extreme weather events, as well as simulations of future climate (Tang, 2019). In recent decades, climate changes have caused impacts on natural and human systems on every continent and across the oceans (IPCC, 2021).

The education agenda in climate change adaptation and mitigation strategies emphasised the necessity of learning new knowledge and skills and modifying behaviour to decrease the vulnerability of the natural and human systems to the impact of climate change (Anderson, 2012). Shepardson et al. (2017) advocate the view that teachers and students need to comprehend the causes and consequences of global warming. This is because education helps show accountable and sensible citizens that they have a severe responsibility to change their daily lifestyle to tackle present sustainability issues, including climate change, that are impacting society (Anderson, 2012; Bofferding & Kloser, 2015; McNeill & Vaughn, 2012; Shepardson, Roychoudhury, & Hirsch, 2017).

Malaysian students were exposed to climate change knowledge during the science and geography lessons. More specifically, climate change is taught in Form 2 science under the topic of Ecosystem and the theme of Maintenance and Continuity of

Life. The topic of Ecosystem focuses on educating students on the interdependence among organisms and the environment to create a balanced nature to ensure the sustainability of living things (Ministry of Education Malaysia (MOE), 2016). The topic includes teaching about climate change, global warming, the greenhouse effect, greenhouse gases, ozone layer depletion, and acid rain. The topic requires students to understand the phenomena to be aware of the causes and effects of climate change and ways to reduce the effect of climate change.

Teaching and delivering climate change concepts is challenging (Tolppanen & Aksela, 2018; Vitale et al., 2016). Due to the abstractness, many studies show that students often develop wrong ideas and misunderstand climate change (Chang, 2014; Gupta et al., 2016). Chang and Pascua (2016) posited that the pedagogy of climate change must be well structured to better conceptualise climate change knowledge among students. Chang (2014) proposed that reforms are needed in the curriculum of climate change education to assist students' learning, overcome misconceptions, and prompt students toward environmentally friendly engagement. Boyes and Stanisstreet (1993) mentioned that well-designed teaching approaches must uphold the issue of climate change in the classroom. A well-designed teaching and learning strategy in climate change education help students develop capabilities as future citizens to possess skills to solve climate change problems (Favier et al., 2021). Chang's study (2014) suggested that educators re-examine instructions in teaching climate change by focusing on and relating the reality of the relevant issue to motivate students to learn more about the topic. Furthermore, Monroe et al. (2019) advocated the importance of bringing climate change issues closer to students to engage with the topic and make it personally relevant to them. Because of its complexity, climate change teaching should be cut across many disciplines (Favier et al., 2021; Tolppanen & Aksela, 2018); thus, climate change teaching and learning cannot be done in silo grounded in a single discipline. Climate change education is currently conducted in Malaysia and other countries as a single discipline (Ahmed et al., 2021; Karpudewan et al., 2015; Lewis & Lu, 2017; Sterman, 2012).

Climate change is a real-world issue with multiple perspectives (Karl et al., 2011; Lehtonen et al., 2019; Levy & Patz, 2015). Effective teaching and learning of climate change require a more pragmatic approach that allows for the direct application of knowledge and skills in a real-world setting (Maner, 2016). This notion parallels the transdisciplinary approach to STEM education introduced by Vasquez et al. (2013). The highest level of integration on the STEM continuum, the transdisciplinary approach, requires students to tackle real-world problems or projects by combining knowledge and skills from two or more dimensions and assisting in the manifestation of their learning experience (Vasquez et al., 2013). Climate change is a real-world problem because it is a massive, complex, and systemic challenge whose consequences are impossible to foresee (Incropera, 2016; Peters & Tarpey, 2019). Hence, the transdisciplinary approach is needed for students to take ownership of their learning and apply their knowledge and skills to solve problems in the real world (Bush & Cook, 2019; Herro & Quigley, 2017; Klein, 2014).

In the wake of the Fourth Industrial Revolution, worldwide awareness of Science, Technology, Engineering and Mathematics (STEM) disciplines from the educational and talent pool sectors has increased exponentially (English, 2016; 2017; Kelley & Knowles, 2016). The main goal of STEM education is for students to develop a well-rounded foundation of skills and perform in the highly connected world (Vasquez et al., 2013). Recent emphasis has been placed on STEM integration; the practise of integrating all disciplines into teaching and learning in schools, to improve

STEM education (Daman Huri & Karpudewan, 2019; Honey et al., 2014). Bryan et al. (2015) defined integrated STEM as “The teaching and learning of the content and practices of disciplinary knowledge, including Science and Mathematics through the integration of the practices of engineering and engineering design of relevant technologies” (p. 23). Teaching integrated STEM is necessary as students will be exposed to contextualised, authentic and meaningful learning experiences (Bryan et al., 2015) that will adequately equip them for what they will attain in real life (Nadelson & Seifert, 2017). In addition, teaching STEM subjects more integrated with real-world problems enhances students’ learning (Honey et al., 2014; Takeuchi et al., 2020). However, concerns arise among STEM educators about integrating the four disciplines efficiently while establishing the originality of each discipline (English, 2017). Another serious concern is how it is possible to establish integration between the disciplines while teaching science lessons (English, 2016; 2017; Honey et al., 2014). An attempt was made to include arts discipline within STEM to STEM to facilitate integration between disciplines (English, 2017) simultaneously to escalate students’ interest and skills in STEM fields (Quigley et al., 2017). The Arts discipline aims to cultivate students’ creativity to connect the disciplines to augment students’ problem-solving skills in real-world settings (Quigley & Herro (2016). However, STEAM education remains elusive due to the absence of a transparent approach to integrating the disciplines (Mejias et al., 2021). Most recent studies documented that Malaysian teachers struggle to effectively implement STEM education because teachers lack appropriate knowledge and skills (Karpudewan et al., 2022a; 2022b; Subramaniam et al., 2022).

Past studies depict that reading and writing are instrumental in enhancing students' conceptual knowledge acquisition in learning science (Cervetti & Pearson, 2018; Osborne, 2010). Reading and writing enforce students to read, write, and communicate their ideas related to science to gain insight and understanding of a particular topic in science (Osborne, 2002). Reading and writing also promote scientific knowledge and skills acquisition through student inquiry (Pearson et al., 2010). Another study indicated embedding various modes of representations such as tables, pictures, diagrams, artefacts, charts and equations within writing engages students in making decisions and arguments (McDermott & Hand, 2013). Situating reading, writing, and various modes within STEM disciplines, which results in the STrEaM approach, enables the establishment of a transdisciplinary perspective by connecting the disciplines (Subramaniam et al., 2022). The transdisciplinary perspective to STEM derived from using STrEaM makes it a viable approach to teaching and learning the climate change phenomena of global warming, greenhouse effect, acid rain and ozone layer depletion, which are multidisciplinary in nature. Lowercase 'r' denotes the reading and writing components, while lowercase 'a' depicts the arts component, which consists of the various representations such as drawings, diagrams, graphs, tables, charts and artefacts embedded in the writing (Subramaniam et al., 2022). The 'a' is different from Arts in STEAM education, whereby the 'A' in STEAM education is meant for humanizing science and technology (Baines, 2015). Scholars and practitioners have different perspectives on Arts in STEAM education, including Arts Education, Arts as any non-STEM discipline, and Arts as a synonym for project-based learning, problem-based learning, technology-based learning, or making (Perignat & Katz-Buonincontro, 2019a).

The technological transformation of teaching and learning has certainly provided exciting opportunities to design learning environments that are realistic, authentic, engaging, and exceptionally fun (Kirkley & Kirkley, 2005). Technology has always held great promise for increasing student engagement and level of understanding of the learning content (Di Serio et al., 2013; McNeal et al., 2014). Computers, multimedia, e-learning, and simulations (Bush et al., 2016; McNeal et al., 2014; Slotta & Linn, 2009; Smith et al., 2019) have been integrated into the educational arena to educate climate change so that students may visualising the phenomena of climate change. In addition, a study done by Svihla and Linn (2012) shows that visualisation can help students learn about complex systems such as climate change (Pruneau et al., 2010; Shepardson et al., 2017; Tolppanen & Aksela, 2018). As one of the emergent technology, AR enables 3D views of the greenhouse effect, global warming, acid rain, and ozone layer depletion, allowing students to experience the phenomena for real by visualising the multiple perspectives embraced within.

Augmented Reality (AR) is an emerging technology that has received incredible attention in various areas, such as the military, medicine, and education. AR is a technology that lets people superimpose digital content (images, sounds, texts) over a real-world environment (Azuma, 1997). AR is a popular technology widely used in educational settings (Kularbphettong et al., 2019). Following the development of context-aware technologies such as mobile phones and tablets, AR has become more robust in becoming an outstanding technology (Dunleavy & Dede, 2014a; Roy et al., 2017). Currently, the augmented mobile reality is one of the most explosive growth areas for AR applications (Craig, 2013). Due to the rising popularity of mobile devices globally, the widespread use of AR on mobile devices such as smartphones and tablets has become a growing phenomenon (Nincarean et al., 2013). A mobile AR application is a type of mobile application that integrates and supplements built-in components in a mobile phone to deliver reality-based services and functions. Mobile AR, as a platform, provides a new direction for technology-aided science teaching and learning (Yang et al., 2018).

Marker-based AR uses the phone camera and certain visual markers (like a QR code or a specific image) to produce augmented images when the camera senses. The 3D depictions of the concepts shown to the students during the teaching and learning process extremely augment their understanding (Roy et al., 2017). Interaction between students and screen in learning content knowledge from the 3D perspective further enhances the quality of learning (Nielsen et al., 2017) as interactivity increases students' attention, engagement, and presence in learning (Cabiria, 2012). In the context of teaching and learning about climate change, AR is instrumental as AR enables viewing 3D representations of climate change phenomena such as the greenhouse effect, global warming, acid rain and ozone layer depletion. The 3D representations of the phenomena allow experiencing the phenomena for real.

The amalgamation of STrEaM-AR to stage the teaching and learning of climate change for Form Two students on a mobile platform gives rise to a teaching and learning approach known as STrEaM-AR-CC. STrEaM-AR-CC, from this point onwards, is a transdisciplinary teaching and learning strategy that visualises the four climate change phenomena in a three-dimensional view simultaneously and provides multiple perspectives on the phenomena.

Previous studies have reported that secondary students held misconceptions about the scientific aspects related to climate change. For instance, students persistently believe that climate change causes acid rain and skin cancer due to exposure to ultraviolet rays (Chang & Pascua, 2015), while some assume that acid rains happen because of the ozone layer depletion or the greenhouse effect (Groves & Pugh, 2002). Additionally, secondary school students usually have alternative conceptions about ozone layer depletion (Pekel & Özay, 2005). Students also held some misconceptions about global warming. Previous studies indicate that students believe the destruction of the ozone layer causes global warming (Andersson & Wallin, 2000; Österlind, 2005; Reinfried et al., 2012; Rye et al., 1997; Shepardson et al., 2009). Students also possess misconceptions about the greenhouse effect. Students associate the greenhouse effect with tectonic plates and believe that the greenhouse effect is related to greenhouses (Reinfried & Tempelmann, 2014).

System thinking is vital to understanding complex system variations, causes and effects (Shepardson et al., 2017) and scientific concepts and principles (Lee et al., 2019). System thinking has pertained as a higher-order thinking skill (Frank, 2002) needed in the field of science, technology, and everyday life (Ben Zvi Assaraf & Orion, 2005), particularly for understanding the complex knowledge of climate change due to the estimation of its long-term effects being unfeasible because of anthropogenic activities (Fanta et al., 2019). System thinking is context-specific, and its definition varies according to the context. An outcome of a study done by Ratinen (2013) defines systems thinking as the ability to recognise, describe and model complex aspects of reality as a climatic system. Ratinen (2013), in another study, additionally emphasises that the crucial aspect of system thinking is the ability to distinguish significant elements of the climatic system and the varied interrelationship between these elements.

Students' systems thinking skills in climate systems were assessed using the two levels in the Sytems Thinking Hierarchical Model; analysis level of systems components (Level 1) and synthesis of systems components (Level 2) (Ben-Zvi-Assaraf & Orion, 2010). At the analysis level, systems thinking refers to students' ability to perform analysis of system components, which comprises the ability to identify system components and processes. Systems thinking at the synthesis level denotes students' ability to perform synthesis of system components, which includes the ability to identify relationships between separate components, to identify dynamic relationships between the system's components, to understand the cyclic nature of systems, and to organize components and place them within a network of relationships (Assaraf & Orion, 2010; Ben-Zvi-Assaraf & Orion, 2010).

According to Shepardson et al. (2012), students' typical linear way of thinking prevents them from recognising the interconnection among the climate system components. Shepardson et al. (2012) further point out that this lack of understanding in connecting climate systems components hinders students from comprehending the causes and effects of climate change and failure to strategise measures for adaptation and mitigation. Students who lack conceptual knowledge in science may demonstrate a lack of system thinking (Lee et al., 2019). Thus, it is necessary to inculcate system thinking skills among students in teaching climate change knowledge. In addition, Assaraf and Orion (2005) reported that most students did achieve meaningful progress in system thinking while possessing only basic initial system thinking abilities.

The relevance of science education contributes to students' intellectual skill development, encourages learner competency for current and future societal participation, and addresses learners' vocational awareness and understanding of career chances (Stuckey et al., 2013). Stuckey et al. (2013) suggested three basic dimensions of the relevance of science education: individual, societal, and vocational dimensions. Each dimension has a spectrum ranging from present to future and comprises intrinsic and extrinsic points of view. Students are required to possess a certain level of scientific knowledge to become well-informed citizens and participate in the socio-scientific discussion (Stuckey et al., 2013), such as global climate change (Kolstø, 2001). Science education's relevance for the individual includes matching the learners' curiosity and interest and providing students with the necessary skills for their everyday lives. The relevance of science education from the societal viewpoint focuses on preparing students for self-determination and a responsibly led life in society by understanding the interdependence and interaction of science and society. In comparison, the relevance of science education in the vocational dimensions is constituted by offering orientation for future jobs and careers, preparation for further academic or vocational training and opening up formal career chances (Stuckey et al., 2013).

Climate change is a contemporary socio-scientific issue relevant to modern society (Sadler, 2011). Three dimensions of relevance related to climate change constitute individual, societal, and vocational dimensions. Individual dimensions refer to students' perceptions reflecting the level of individual concerns and awareness to cope with climate change in their everyday lives. Next, societal dimensions signified students' level of societal viewpoint on the issue of climate change and their competency in contributing to society's sustainable development. Finally, the vocational dimension implies students' level of interest in preparing for other academics and career-related to climate change mitigations and adaptations.

Reducing or overcoming misconceptions about climate change, improving systems thinking skills in relation to climate change, and the relevance of science education with teaching and learning climate change across the three levels require exposing students to multiple perspectives on climate phenomena. The STrEaM-AR-CC is a transdisciplinary approach that enables a 3D view of climate change phenomena that overcomes the idea that science concepts are abstract, dull and difficult to learn. The approach would enable students to cross the four disciplines to construct their own knowledge and build on their existing knowledge related to climate change. STrEaM-AR-CC is a teaching and learning approach that allows climate change to be taught across all disciplines, subsequently instilling system thinking skills among students. STrEaM-AR-CC, a transdisciplinary teaching and learning approach, is deemed suitable for preparing and nurturing students to be mindful citizens who have a collective responsibility towards the environment. Students will be exposed to the real-world global climate change problem faced by the society around them. This might impose them to help mitigate the effect of climate change happening globally and locally.

1.3 Statement of the Problem

Numerous studies mentioned that, while learning about climate change, most secondary school students consistently perceive climate change disparately from the scientists' view and tend to grasp misconceptions (Chang & Pascua, 2016; Deignan et al., 2019; Heng et al., 2017; Lee et al., 2020). Misconceptions occur commonly in various areas related to climate change. For instance, in ozone layer depletion (Boyes & Stanisstreet, 1997; Chang & Pascua, 2016; Hansen, 2010; Österlind, 2005; Reinfried & Tempelmann, 2014; Varela et al., 2018); in global warming (Karpudewan et al., 2015; Reinfried et al., 2012); in greenhouse effect (Heng et al., 2017; Karpudewan et al., 2015; Reinfried & Tempelmann, 2014) and acid rain (Chang & Pascua, 2015; Groves & Pugh, 2002).

Climate is a naturally complex system (Shepardson et al., 2017) that is challenging to grasp and is related to systems thinking (Fanta et al., 2019). A considerable number of studies have examined students' abilities to think in the context of systems (Assaraf & Orion, 2010; Ben-Zvi-Assaraf & Orion, 2010; Liu & Hmelo-Silver, 2009; Roychoudhury et al., 2017). Little literature has been published on studies that review how students conceptualise the climate system using system thinking (Shepardson et al., 2017). Roychoudhury et al. (2017), in their study, proposed that understanding climate change should also comprise an understanding of the climate system. Up to this end, no studies have addressed climate change understanding and environmental education in terms of systems thinking in Malaysia.

The relevance of science education to students is instrumental in ensuring students acquire the contemporary knowledge and skills necessary to become scientifically literate citizens (Robert et al., 2014; Stuckey et al., 2013). Lack of relevance in science education content hinders effective teaching and learning. Current literature shows that the content taught in schools lacks relevance for students to address the challenges they encounter daily (Aminah & Yoong, 2005; Belova et al., 2017a; Rannikmae et al., 2010; Schreiner & Sjøberg, 2004a). The current science education focuses on memorising and rote learning, based entirely on the textbook and is merely exam-oriented (Halim & Meerah, 2016; Karpudewan et al., 2015). Science instructions in the classroom today are still conducted in a manner where students are not given enough opportunity to relate and interact with vital local and global issues happening around them, such as climate change that impacts their daily lives (Sias et al., 2017). This results in students learning content knowledge irrelevant to their real life. Although climate change has been integrated, the relevance of climate change education is not yet established. A limited body of knowledge attempted to probe perceptions of students' relevance to climate change. Addressing gaps related to students' relevance to climate change education regarding climate change teaching and learning would likely result in more effective learning.

The prevalence of misconceptions, lack of system thinking skills and relevance mainly occurs due to the nature of teaching and learning climate change in the silo as a single discipline (Ahmed et al., 2021; Karpudewan et al., 2015; Lewis & Lu, 2017; Sterman, 2012). For example, the teaching and learning about climate change that occurs during Ecosystem lessons (Ministry of Education Malaysia (MOE), 2016) solely focus on science discipline and overlook other disciplines that are interconnected to the topic. Learning about climate change as a single discipline hinders students from comprehending the interconnections between the four phenomena and humans' daily lives (Favier et al., 2021). This subsequently leads to the development of misconceptions among students. Presenting climate as a compartmentalised system rather than a single system connected to multiple disciplines impedes students from synthesising and analysing the components of the systems (Assaraf & Orion, 2010; Jacobson et al., 2017; Sterman & Sweeney, 2002). The relevance of science education to contemporary needs is also affected by monodisciplinary teaching (Perkins et al., 2018). Students often perceive climate change phenomena as abstract and distant because teaching and learning are conducted separately and not in an interdisciplinary manner (Favier et al., 2021; Jorgenson et al., 2019; Rousell & Cutter-Mackenzie-Knowles, 2020).

Some studies suggest infusing integrated STEM teaching to reflect interdisciplinary teaching and learning(Daman Huri & Karpudewan, 2019; English & King, 2019). However, integrating STEM teaching and learning is complex and challenging for teachers (Ismail et al., 2019; Khozali & Karpudewan, 2020). Factors such as ambiguous definitions of STEM education and teachers trained to teach science as a single discipline contribute to the lack of knowledge to execute interdisciplinary teaching (Breiner et al., 2012; Bybee, 2010; Li, 2018). In particular, teachers are not informed about how to integrate the four STEM disciplines during a science lesson (Ismail et al., 2019; King & English, 2016). Expanding STEM to STrEaM is one way of executing the interdisciplinary approach, and this is also appropriate to deliver multiperspective issues such as climate change.

As the Fourth Industrial Revolution (4th IR) encompasses the global trend, attempts have been made to 4 IR in education. Some studies have infused technology-based learning, such as information communication technologies, simulations, e-learning, and web 2.0 to enhance learning (Bush et al., 2016; Libarkin et al., 2018; Luna, 2011; Svihla & Linn, 2012a; Vitale et al., 2016) is documented. However, despite these initiatives, students struggle to conceptualise the climate system. This happens because the existing technology does not permit visualisation of the phenomena related to climate change. Augmented reality (AR), on the contrary, allows three-dimensional (3D) viewing (Ibáñez & Delgado-Kloos, 2018) and visualisation of the phenomena (Chang et al., 2016; Wu et al., 2013) coupled with an interactive way of learning possibly improve the learning about climate change. Thus, learning climate change in science subjects assisted by AR technology, one of the pillars in 4th IR that permits interaction with the real world, is imperative to allow contextualised, authentic, and meaningful learning among students. Nonetheless, recent literature, particularly in the context of climate change instructions in Malaysia, has not given much interest in allowing the versatility of AR as a learning technology that enables students to interact with 3D virtual and real objects simultaneously in real-time.

The combination of STrEaM, AR, and climate change is completely new and requires further investigation. It is an approach that allows students to learn from multiple dimensions, which is appropriate to reduce misconceptions and improve systems thinking and the relevance of science education.

1.4 Purpose of Study

This study aims to develop the STrEaM-AR approach for teaching and learning climate change and to measure the effectiveness of STrEaM-AR-CC in reducing Form Two students misconceptions on climate change, improving systems thinking skills and perception of the relevance of science education.

1.5 Research Objectives

The objectives of the research are as follows:

1. To explore the current teaching and learning practices of climate change on the topic of Ecosystem.
2. To develop STrEaM-AR-CC teaching and learning approach to teach climate change to Form Two students.

3a. To measure the effectiveness of STrEaM-AR-CC in reducing Form Two students' misconceptions about climate change.

- i) To measure the effectiveness of the STrEaM-AR-CC approach in reducing Form Two students' misconceptions about global warming

ii) To measure the effectiveness of the STrEaM-AR-CC approach in reducing Form Two students' misconceptions about the greenhouse effect

iii) To measure the effectiveness of the STrEaM-AR-CC approach in reducing Form Two students' misconceptions about ozone layer depletion

iv) To measure the effectiveness of the STrEaM-AR-CC approach in reducing Form Two students' misconceptions about acid rain

3b. To explore how students' misconceptions of climate change differ before and after using the STrEaM-AR-CC teaching and learning approach.

4a. To measure the effectiveness of the STrEaM-AR-CC teaching and learning approach in improving Form Two students' systems thinking skills

i) To measure the effectiveness of the STrEaM-AR-CC in improving Form Two students' systems thinking skills in Level 1: analysis of system components

ii) To measure the effectiveness of the STrEaM-AR-CC in improving Form Two students' systems thinking skills in Level 2: synthesis of system components

4b. To explore how students' systems thinking skills differ before and after the STrEaM-AR-CC teaching and learning approach.

5a. To measure the effectiveness of the STrEaM-AR-CC teaching and learning approach in improving Form Two students' perception of the relevance of science education in climate change

i) To measure the effectiveness of the STrEaM-AR-CC in improving Form Two students' perception of the relevance of science education in climate change from the individual dimension

ii) To measure the effectiveness of the STrEaM-AR-CC in improving Form Two students' perception of the relevance of science education in climate change from the societal dimension

iii) To measure the effectiveness of the STrEaM-AR-CC in improving Form Two students' perception of the relevance of science education in climate change from the vocational dimension

5b. To explore how students' perceptions of the relevance of science education differ before and after the STrEaM-AR-CC teaching and learning approach.

1.6 Research Questions

The research questions for this study are as follows:

1. What are the current practices of teaching and learning climate change employed during the lessons on the Ecosystem?
2. How do the findings of RQ1 guide the development of the STrEaM-AR-CC teaching and learning approach?

3a. Is there any significant difference between the control and experimental group's linear combination of post-test misconceptions on climate change mean scores?

i) Is there any significant difference between the control and experimental group's post-test mean scores for misconceptions about global warming?

ii) Is there any significant difference between the control and experimental group's post-test mean scores for misconceptions about the greenhouse effect?

iii) Is there any significant difference between the control and experimental group's post-test mean scores for misconceptions about acid rain?

iv) Is there any significant difference between the control and experimental group's post-test mean scores for misconceptions about ozone layer depletion?

3b. How do the students' misconceptions of climate change differ between the pre and post-interview?

4a. Is there any significant difference between the control and experimental group's linear combination of post-test for systems thinking skills mean scores?

i) Is there any significant difference between the control and experimental group's post-test mean scores for systems thinking skills in level 1(analysis of system components)?

ii) Is there any significant difference between the control and experimental group's post-test mean scores for systems thinking skills in level 2 (synthesis of system components)?

4b. How do the students' systems thinking skills differ between the pre and post-interview?

5a. Is there any significant difference between the control and experimental groups linear combination of post-test for the perception of the relevance of science education mean scores?

i) Is there any significant difference between the control and experimental group's post-test mean scores for the perception of the relevance of science education from the individual dimension?

ii) Is there any significant difference between the control and experimental group's post-test mean scores for the perception of the relevance of science education from the societal dimension?

iii) Is there any significant difference between the control and experimental group's post-test mean scores for the perception of the relevance of science education from the vocational dimension?

5b. How do the students' perceptions of the relevance of science education differ between the pre and post-interview?

1.7 Hypotheses

Based on the research questions, the following hypotheses were formulated:

Misconceptions about Climate Change

$H_0 3$: There is no significant difference between the control and experimental group's linear combination of post-test for misconceptions on climate change mean scores.

$H_0$3a: There is no significant difference between the control and experimental group’s post-test mean scores for misconception on global warming.

$H_0$3b: There is no significant difference between the control and experimental group’s post-test mean scores for misconception on the greenhouse effect.

$H_0$3c: There is no significant difference between the control and experimental group’s post-test mean scores for misconception on ozone layer depletion.

$H_0$3d: There is no significant difference between the control and experimental group’s post-test mean scores for misconception on acid rain.

Systems thinking

$H_0$4: There is no significant difference between the control and experimental groups linear combination of post-test for systems thinking skills mean scores.

$H_0$4a: There is no significant difference between the control and experimental group’s post-test mean scores for systems thinking skills in level 1 (analysisof system components).

$H_0$4b: There is no significant difference between the control and experimental group’s post-test mean scores for systems thinking skills in level 2 (synthesis of system components).

Relevance of Science Education

$H_0$5: There is no significant difference between the control and experimental group’s linear combination of post-test for the perception of the relevance of science education mean scores.