AnSSI-Based STEAM Approach to Developing Science Programs

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Abstract

This study employed a multi-phased process to guide the development of an approach for integrating socio-scientific issues (SSI) and science, technology, engineering, arts, and mathematics (STEAM) education in a way that can reform how science is taught in schools to improve scientific literacy. This approach can help teachers connect science authentically to real-world issues that have social and cultural relevance to students’ everyday lives. To demonstrate how the approach could be used for curriculum
development, the authors defined the dimensions and key principles of SSI-based STEAM teaching and translated the approach into a climate change program by using a 6E inquiry model, which emphasizes an “enactment” stage. This program was used to discuss the benefits and challenges of employing an SSI-based STEAM approach in classroom contexts. We conclude by discussing implications for using this approach to improve science learning opportunities in cross-cultural contexts, and we raise questions about the need for future research.

Keywords

6E inquiry model – global citizenship – socio-scientific issues – SSI – STEAM

1 Introduction

In recent years, science, technology, engineering, arts, and mathematics (STEAM) education has been identified as a potential pedagogical approach for reforming the science curriculum to better prepare students for the 21st century. STEAM is an interdisciplinary educational approach that helps enrich and extend students’ experiences in science learning by integrating the arts disciplines (Katz-Buonincontro, 2018). Integrating art topics such as intercultural learning into science allows teachers to provide more connected, meaningful, and interesting ways to learn (Chu et al., 2019). This is because arts-related practices and perspectives appeal to students’ interest by creatively reframing and promoting the exploration of the social and humanistic dimensions inherent in science (Abed, 2016; French, 2019). This moves the learning beyond purely science concepts and has been found to encourage greater student participation, motivation, and the development of skills such as creativity (Ozkan & Topsakal, 2019). Hyater-Adams et al. (2018) claimed that students became more engaged and motivated to participate in their science learning because STEAM facilitated more opportunities for student agency, autonomy, and exploration of identity. Furthermore, STEAM should also facilitate opportunities for learners to reinterpret their understanding and representation of science through creative means (Abed, 2016). This involves the use of student-centered strategies such as hands-on tasks, collaboration, group discussion, and inquiry-based learning (Thuneberg et al., 2018).

However, at the secondary school level, many teachers struggle to plan and implement STEAM in a way that authentically connects to students’ everyday lives (Herro et al., 2019; Kang, 2019; Kim & Lee, 2018). Kang (2019) suggested that
one reason may be that many secondary high school teachers tend to strongly emphasize the science content over connections to other multiple disciplines. On the other hand, Quigley and Herro (2016) and Hadinugrahamingsih et al. (2017) found that students found it difficult to engage with and connect deeply to the real-world issues explored in STEAM. Authentic STEAM learning requires students to explore real-world challenges that are socially and culturally relevant to them and connects naturally across various disciplines (Huser et al., 2020).

The lack of authenticity in STEAM and disconnections between students’ science learning and their everyday lives has been found to have negative effects on students’ conceptual understanding, skills, values, and attitudes and hence on their scientific literacy (Harker-Schuch & Bugge-Henriksen, 2013; Quigley et al., 2020). This is a major concern because the scientific performance data from the Programme for International Student Assessment (PISA) illustrate that scientific literacy has been steadily declining over the last few years (Organization for Economic Cooperation and Development [OECD], 2021). These trends have been observed in many OECD countries including Australia, Korea, Canada, and New Zealand (OECD, 2021). In response to the decline in scientific literacy and the challenges that teachers face in using STEAM to authentically connect science to students’ daily lives, there have been suggestions to integrate socio-scientific issues (SSI) into STEAM practices (Colucci-Gray et al., 2016; Won et al., 2021). The research presented here was developed by researchers in both Australia and Korea with the collaborative goal of developing a program designed to improve students’ scientific literacy while also expanding opportunities for students to learn about science in the context of the larger world around them.

1.1 The Gaps in STEAM

Studies have shown that contextualizing science concepts in authentic real-world scenarios enables students to see the relevance and meaningfulness of science to their lives (French, 2019; Kim & Song, 2013). This is an aspect that current STEAM practices are struggling to achieve authentically because the real-world problems are often chosen simply to meet the outcomes set for the curriculum (Quigley et al., 2020). These types of choices may result in disregard of students’ social and cultural contexts, thus making it difficult for them to perceive the connection that science or real-world problems have to their daily lives (Quigley et al., 2020).

The connection and relevance of the real-world scenarios used in STEAM can become further distorted if the real problem is presented and taught in a manner that drives students to consider only one perspective or solution...
(Harker-Schuch & Bugge-Henriksen, 2013; Connor et al., 2015). This removes the possibility of seeing that many real-world problems in everyday life and society may draw on knowledge and skills from various disciplines (Lin & Tsai, 2021). Consequently, this limits students’ capacity to actively draw on and apply interdisciplinary and integrative skills and thinking (Connor et al., 2015). In these situations, students are likely to struggle to develop the appropriate socio-cultural and political attitudes and the independent thinking needed to solve real-world problems (Harker-Schuch & Bugge-Henriksen, 2013). These attitudes and critical independent thinking are crucial to empowering students to engage in personal and civic decision making and global citizenship (Zandvliet, 2018).

1.2 **Rationale for Integrating SSI into STEAM**

Only through engagement with authentic and relevant real-world issues will students gain the awareness and sensitivity needed to handle the socio-cultural issues embedded in their everyday lives (Colucci-Gray et al., 2016). In STEAM, there needs to be a way to integrate socio-cultural contexts that can make deep connections between students’ learning and their lived experiences and thus redefine how students view the relationship between science and society (Colucci-Gray et al., 2016). To address this gap, this study proposes that there is room to integrate SSI into current STEAM practices.

The term “SSI” refers to social dilemmas that have strong linkages to science, technology, and ethical and moral dimensions (Çalık & Karataş, 2019). Contextualizing science learning with SSI can help address these challenges in STEAM by helping to bring in real-world problems that have socio-cultural and emotional relevance to students (Ottander & Ekborg, 2012). Several studies have demonstrated that SSI can have positive effects on students’ conceptual understanding and the development of skills such as perspective taking, argumentation, and moral reasoning (Akerblom & Lindalh, 2017; Zeidler, 2016). Furthermore, SSI help students to process new ideas, interests, and values that not only contribute to enhancing scientific literacy but also their sense of global citizenship (Sadler et al., 2017; Lee et al., 2013). Bringing in an SSI perspective can help to enhance STEAM practices; however, STEAM also has the potential to improve how SSI are taught. Many teachers and researchers believe that introducing SSI is an important component for learning science (Tsai, 2018). However, teachers often experience difficulties with selecting relevant SSI topics, using student-centered strategies, and determining the roles of the teacher and student in the learning process (Bossér et al., 2015; Hancock et al., 2019). STEAM’s strong emphasis on interdisciplinary knowledge and student-centered strategies can compensate for the shortcomings in SSI.
The difficulties that teachers face in implementing either SSI or STEAM as stand alone approaches could be minimized by integrating both approaches together. The integration of SSI is needed to bring new ways for students to think about how society uses and relates science to global problems, which can enable them to be able to propose and innovate sustainable solutions (Colucci-Gray et al., 2016). SSI respond to the moral and ethics side of science learning and bring in new and challenging social knowledge (Siribunnam et al., 2019). On the other hand, STEAM introduces the interdisciplinary understanding needed for students to understand real-world problems, make informed decisions, and engage in meaningful discourse (Johnson et al., 2020). SSI and STEAM have different educational aims; however, both approaches emphasize the importance of convergence between multiple perspectives and disciplines in the real-world context (Choi et al., 2021). SSI-STEAM integration becomes further possible because these approaches both heavily stress the use of social constructivist learning, situated learning, and inquiry-based learning as prominent teaching approaches.

Using the social constructivist approach emphasized in SSI and STEAM, teachers can facilitate opportunities that allow students to co-construct their knowledge with others in a space that encourages differences in values and perspectives and exchanges of ideas (Presley et al., 2013; Schreiber & Valle, 2013). This approach recognizes that the social and cultural interactions and experiences of a learner play a significant role in how they learn and assign meaning to their own reality and experiences (Vygotsky, 1978, p. 57; Schreiber & Valle, 2013). In reflecting the social constructivist perspective of learning, both SSI and STEAM frequently employ inquiry-based instructional models such as the 5E inquiry model by Bybee et al. (2006). The 5E model directs students through the processes of engaging, exploring, explaining, elaborating, and evaluating to help students develop their curiosity and initial understanding about a problem. It then teaches them to develop the skills needed to investigate, evaluate, and apply their new knowledge and skills to solve the problem (Bybee, 2019).

Common inquiry-based strategies used in both SSI and STEAM include collaborative learning and hands-on tasks. Inquiry-based learning helps to enhance students’ capacity for interdisciplinary thinking and integrated practices related to STEAM learning (Kim et al., 2012, as cited by Hong et al., 2020). In SSI it has been found to promote stronger skills for exploration, argumentation, and the negotiation of social, cultural, moral, and ethical dimensions (Presley et al., 2013).

Another educational learning approach that can enable SSI to be integrated into STEAM is the emphasis on situated learning found in both approaches.
Situated learning highlights that knowledge construction is influenced by the specific content and cultures in which they are constructed (Brown et al., 1989). Integrating SSI into STEAM can enhance the authentic tasks and contexts already present in STEAM practices and thus help students to understand how science is related to the different settings in their lives (Sadler, 2009). The authentic tasks and settings need to enable students to put into action how they apply and transfer their knowledge and skills into new contexts and how they enact different views and roles in society (Leung et al., 2018; Ünal & İnan, 2010).

The common emphasis on these three education approaches demonstrates how SSI can be integrated into STEAM. This SSI-based STEAM approach can help provide teachers with an innovative way to teach science that equally emphasizes the importance of cognitive, emotional, and social learning (Colucci-Gray et al., 2016). Choi et al. (2021) demonstrated that using an SSI-based STEAM approach had a positive impact on students’ climate change literacy, socio-emotional capabilities, and skills such as communication. However, Won et al. (2021) found that teachers struggled to plan and implement SSI-based STEAM programs effectively due to their lack of experience with those programs. Furthermore, to date, there have been no instructional guidelines for SSI-based STEAM that have been developed to support teachers in planning and teaching when using this approach. This makes it difficult for teachers to visualize how SSI and STEAM could converge cohesively to provide better learning opportunities for students.

1.3 The Need for a Theoretical Model
Existing literature on SSI-based STEAM demonstrates that an integrated approach can lead to improvements in domains such as students’ conceptual understanding, creativity, divergent and convergent thinking, and perspectives (Choi et al., 2021; Lee, 2016; Madden et al., 2013). However, these studies have lacked specificity on how teachers can implement the pedagogies and practices that employ SSI-based STEAM learning. Therefore, the question that emerges is what dimensions and principles of SSI-based STEAM do teachers need to implement and how do they do it? In implementing SSI-based STEAM, teachers need to be provided with a guideline that can direct how they organize and implement the approach in the classroom. This approach should help teachers identify the key competencies and principles that need to be addressed when planning and teaching an SSI-based STEAM curriculum or programs. Additionally, the approach should account for the teacher’s role in teaching and learning and how the content can be organized to better optimize learning.
SSI frameworks such as Presley et al. (2013) and STEAM frameworks such as Chu et al. (2021) can be used to help inform the development of our integrated SSI-based STEAM approach. For example, Chu et al. (2020) proposed a STEAM model that used the 5E model to develop an intercultural STEAM program. Presley et al. (2013) proposed that effective SSI instruction needs to embed the core aspects of design elements, learner experiences, and teacher attributes within the classroom environment and in relation to peripheral influences. As mentioned previously, there is no existing approach for SSI-based STEAM that can provide this guidance for teachers who are interested in this approach.

1.4 The Significance of This Study

This study proposes that there is a need to integrate an SSI perspective into STEAM teaching and learning. However, studies have indicated that teachers’ ideas about SSI-based STEAM teaching can be narrow and limited (Won et al., 2021). The significance of developing this SSI-based STEAM approach is that it provides teachers with information on the elements that need to be addressed in an SSI-based STEAM approach. Teachers will be provided with more explicit directions on how they can translate the approach into program development. Developing these types of programs could also enable teachers to address the broader issue of declining scientific literacy. There have been many debates on what scientific literacy entails because of the diverse interpretations of the term. Roberts (2007) highlights that the different viewpoints of scientific literacy can be categorized into two broad visions. Vision I emphasizes the need to develop students’ scientific knowledge, processes, and skills (Roberts, 2011). Vision II emphasizes that science needs to be contextualized in real-world events to enable students to gain meaning from their learning (Roberts, 2011).

However, Roberts’ Vision I and Vision II do not have any curriculum emphasis for socio-political action, values, and existential perspectives (Sjöström et al., 2017). These elements are crucial to the development of morally and ethically informed decisions, which are framed as a core focus in many science curricula around the world (Sjöström et al., 2017; Siribunnam et al., 2019). This has led to the broadening of the definition of scientific literacy to include an additional third vision. Vision III emphasizes the need to nurture students to become global citizens by developing their socio-cultural and socio-political perspectives, values, and actions (Sjöström et al., 2017).

Using an SSI-based STEAM approach can help to achieve Vision III by making science learning more relatable through holistic experiences that place equal emphasis on emotional learning, values, systematic thinking, and multiple perspectives (Sjöström et al., 2017; Sjöström & Eilks, 2018). This in turn helps nurture students’ capabilities to engage as socio-cultural and -political
participants in the real and complex world, while also using their sense of empathy and multiple perspectives when they make decisions for themselves (Wickman et al., 2012). Additionally, students can learn to understand how many real-world issues are handled in society from a wider perspective (Sjöström & Eilks, 2018).

The challenges that STEAM faces, as outlined in this paper, indicate that teachers struggle to adopt STEAM in a way that can enable them to achieve Vision II authentically and adequately (Harker-Schuch & Bugge-Henriksen, 2013; Herro et al., 2019; Zeidler, 2016). On the other hand, Vision III is often neglected or addressed narrowly because of the struggles that teachers experience trying to achieve it in their classrooms (Hadinugrahaningsih et al., 2017). The approach in this paper is aimed at assisting teachers interested in new and innovative ways to enhance their teaching practices and learning outcomes in science.

1.5 Purpose of This Study
Our goal is to provide an approach that can be used by teachers to plan and implement SSI-based STEAM teaching and learning. This approach will explicitly define the dimensions and key principles of an SSI-based STEAM approach and will apply a newly proposed 6E inquiry model that extends Bybee’s 5E inquiry model (Bybee et al., 2006). Both the approach and 6E inquiry instructional model have guided the development of an SSI-based STEAM program on climate change. To develop this approach, this study explores two important questions:

RQ1. What overlapping theoretical principles in SSI and STEAM can be used to inform the development of an SSI-based STEAM approach?
RQ2. How would the key principles of the SSI-based STEAM approach translate into program development?

2 Methodology
The study employed a multi-phase development process based on design-based research (DBR) methodology (Brown, 1992) to guide the development of the SSI-based STEAM approach. Similar to the DBR method, this study involved the implementation of three interconnected phases (see Figure 1; Plomp, 2007): (1) preliminary research, (2) prototyping, and (3) assessment. Phase 1 focused on preliminary research to identify key outcomes targeted by
the program and learning theories and overlapping dimensions found in SSI and STEAM literature. Phase 2 focused on developing the SSI-based STEAM approach, receiving feedback from expert panel members, and developing the 6E inquiry instructional model. In addition, this phase included the development of a program evaluation rubric that was shared with and used by members of an expert panel to provide feedback about the approach. The final step of the prototyping phase involved the development of lessons and materials that could be used to teach SSI- and STEAM-related content in real classrooms. Phase 3 focused on refining the design artifacts based on feedback.
from members of the expert group, and the strengths and weaknesses were identified based on assessment from the program evaluation rubric.

In comparison to the DBR method, the multi-phase development process did not include the implementation of the study in a specific educational context and setting that involved the classroom teacher, students, and the school (Cobb et al., 2003). The exclusion of this stage in the process was due to the ongoing restrictions imposed by the COVID-19 pandemic. This modified version of the DBR method was selected because it emphasized the importance of forming a theory and collaborating with experts to create design artifacts that can be used by teachers (Anderson & Shattuck, 2012; The Design-Based Research Collective, 2003). These elements were an integral part of the development of an approach that can be used by teachers to create SSI-based STEAM programs. Hence, this was a suitable method for this study. In the sections that follow, we describe each phase of the development process in more detail.

2.1 Preliminary Research Stage
Because the study aimed to use the proposed approach to develop an SSI-based STEAM program, a relevant and compelling SSI needed to be selected as a central topic for the program. Considering the climate crisis that was being directly experienced by Australian students at that time, it was decided that climate change was a suitable topic. The Australian Science Curriculum and relevant literature were then carefully analyzed to identify related science outcomes and other cross-curriculum connections to arts disciplines. Following the curriculum analysis, literature addressing SSI and STEAM approaches, development studies, and theoretical approaches and principles were extensively reviewed to identify overlapping dimensions and key theoretical principles in teaching practices. A search of relevant terms generated 27 relevant peer-reviewed articles that were collected from multiple databases such as ProQuest and SpringerLink (see Figure 2). Through the review, the overlapping
elements found in SSI and STEAM were identified and organized into different categories. However, to translate the approach into a program, it was clear that an instructional model was needed. Based on the emphasis on the 5E model in both SSI and STEAM literature, it was determined that the 5E inquiry-based instructional model by Bybee et al. (2006) would guide the development of the approach.

2.2 Prototyping Stage

From the extensive literature, the study was able to draw out similar dimensions and key principles that were emphasized in both the SSI and STEAM approaches. This information was used to drive an iterative cycle of design, evaluation, and refinement to produce an approach that was used to guide program development. Initially, the 5E inquiry model was used to translate the approach into a climate change program. However, using this model proved challenging because it neglected to provide concrete opportunities for students to put in practice the values and socio-cultural and -political practices that they learn about. These two elements are important determinants in how and what knowledge is used in processes such as decision making and argumentation and thus the development of learners’ sense of global citizenship (Clement, 2012).

As a result, further preliminary research was conducted to understand the different phases in the learning cycle that are presented by other inquiry models such as the 3E, 4E, 6E, and 7E models (Marshall et al., 2008). This initial research into different inquiry models was also done in consideration of the five core features of classroom inquiry (see Table 1; National Research Council [NRC], 2000, p. 25).

| Core features of classroom inquiry |
|----------------------------------|
| 1. Learners engage with scientifically oriented questions that evoke curiosity. |
| 2. Learners focus on evidence by collecting and analyzing data. |
| 3. Learners formulate explanations based on evidence. |
| 4. Learners connect and evaluate their explanation against accurate scientific knowledge. |
| 5. Learners reflect on and then communicate and justify their explanations. |

Note: Adapted from Inquiry and the National Science Education Standards: A Guide for Teaching and Learning (National Research Council, 2000, p. 25).
This led to the addition of a sixth stage known as “enact,” resulting in the development of a 6E inquiry model. This 6E model was used as the main instructional model for program development. Due to the change in the inquiry model used, the resources and lessons that were gathered initially needed to be modified to better reflect the 6E inquiry model. An evaluation rubric was also developed to assess how well the SSI-based STEAM approach would translate to program development. The rubric was initially drafted based on how well the 6E inquiry stages aligned with the SSI-based STEAM principles targeted.

This stage involved three series of initial developments and consultation with an expert group. The expert panel consisted of six researchers with expertise in science education, SSI, STEAM, and curriculum development. The experts used an electronic response survey system to provide feedback and critique about the SSI-based STEAM theoretical approach and the developed lessons and material resources. In addition, the panel members participated in one-on-one and small-group online interactive meetings to help validate the approach and to discuss the issues identified using the evaluation rubric, provided feedback on the strengths of the design artifacts, and gave valuable input for improvements to help produce stronger design artifacts. The experts also reviewed lessons and materials developed using the SSI-based STEAM approach and evaluated the materials using the evaluation rubric provided to give targeted feedback about the alignment of the prototype lessons and material resources to the SSI-based STEAM approach we had theorized. In this way, we sought to develop practical materials based on the conceptual approach we had designed.

2.3 Assessment Stage
The final stage involved the use of the program evaluation rubric by the researchers and a subset of expert panel members to assess the newly developed lesson plans and material resources to determine how well they aligned with our theorized approach and the instructional 6E model. To help determine how the developed lessons and material resources compared to other similar programs, the evaluation rubric was also used to assess five other programs. This provided valuable feedback on the strengths and weaknesses of the design artifacts and thus encouraged further reflection on possible improvements. The reflection and evaluation process also helped to generate recommendations for future studies and practices.
3 The SSI-Based STEAM Approach

Based on the review of SSI and STEAM literature, this study proposes an SSI-based STEAM approach as shown in Figure 3. The proposed approach was developed around learning theories, pedagogies, and key dimensions that are emphasized in both SSI and STEAM learning. Building the approach on key theories, pedagogies, and dimensions found in SSI and STEAM can help lead teachers to better support students’ achievement of targeted learning outcomes.

![Figure 3: SSI-based STEAM-integrated approach](image)

*Note: This model shows three core dimensions of the SSI-based STEAM approach. There are four key principles embedded in the second core dimension of this model.*
Figure 3 illustrates inner, middle, and outer rings that represent the three key levels related to SSI-based STEAM teaching. Learners as active participants are positioned in the inner ring to emphasize the crucial need to develop educational experiences that structure and support students to participate actively in their own learning. To create education experiences that foster students’ active engagement, teachers need to address four key principles of SSI-based STEAM teaching and learning when they plan and arrange the activities in their program. These key principles are located in the middle ring: enacted values and practices, affective learning, authentic context and activities, and interdisciplinary thinking and integrated practices. In the outer ring, educational pedagogical approaches are positioned to highlight that the activities arranged by teachers need to be grounded in the learning theories of social constructivist learning and situated learning and the pedagogical approach of inquiry-based learning. These series of rings illustrate how students, teaching and learning dimensions, and theories and pedagogies are translational and part of an integrated system. In the following sections, we introduce and describe the importance of each key level in greater detail.

3.1 Learners as Active Participants

At the core of the SSI-based STEAM approach, learners are situated centrally as active participants to promote their involvement and engagement in their own learning experiences. This dimension focuses on fostering an environment that promotes greater opportunities for students to take on roles that allow them to be autonomous and thus agents of learning who can express their own voices (Cavagnetto et al., 2020; Furtak & Kunter, 2012). By giving students greater autonomy and agency, teachers shift the responsibility and accountability to students to independently manage and make decisions about their learning (Furtak & Kunter, 2012). Students feel more ownership of their learning and are thus more motivated to invest in their own learning processes (Cavagnetto et al., 2020).

Greater student autonomy and agency provides a safe learning environment where students recognize that they can safely express their opinions and perspectives and understand those of others (Laux, 2018). This process helps students to negotiate and determine the ideals and identities that they enact as participants in society (Alderman & MacDonald, 2015). Furthermore, this creates a context where students can develop a stronger sense of values and competencies and subsequently improve their conceptual understanding and performance (Alderman & MacDonald, 2015; Cavagnetto et al., 2020).
3.2 Key Principles of SSI-Based STEAM Teaching and Learning

The second level of the SSI-based STEAM approach addresses four essential principles of teaching and learning. Based on the review of SSI and STEAM literature, it was found that there were several overlapping teaching and learning practices, such as emotional experiences, interdisciplinary knowledge, real-world application, action learning, and integrated practices (Bati et al., 2018; Chu et al., 2019; Lee & Brown, 2018; Macalalag et al., 2020). These practices were strongly related to how social constructivist learning, situated learning, and inquiry-based learning were emphasized in both approaches, as previously described. Based on these common practices and educational learning approaches found in SSI and STEAM, four key principles were outlined: (1) enacted values and practices, (2) affective learning, (3) authentic context and activities, and (4) interdisciplinary thinking and integrated practices (see Table 2). Although these principles have been represented separately, it is important to note that they are interconnected. Each level is described in this section.

| Key principle                          | Definition                                                                                      | Objective                                          |
|---------------------------------------|-------------------------------------------------------------------------------------------------|----------------------------------------------------|
| Enacted values and practices           | This principle focuses on providing opportunities for acting on values and social practices.     | - Evoking student empowerment                       |
|                                       |                                                                                                | - Providing opportunities to enact different identities |
|                                       |                                                                                                | - Developing positive socio-cultural attitudes and values |
| Affective learning                     | This principle focuses on how students feel during their learning experiences.                   | - Creating emotional connections                    |
|                                       |                                                                                                | - Evoking student interest and curiosity            |
| Authentic context and activities       | This principle focuses on connecting students' knowledge and skills to relevant and meaningful contexts and activities. | - Examining real-world problems                     |
|                                       |                                                                                                | - Providing socio-cultural context                  |
|                                       |                                                                                                | - Performing real-world tasks                       |
| Interdisciplinary thinking and integrated practices | This principle focuses on enhancing students' ability to draw and apply knowledge and practice from multiple disciplines. | - Drawing on interdisciplinary knowledge and perspectives |
|                                       |                                                                                                | - Applying integrated practices from multiple disciplines |
3.2.1 Enacted Values and Practices
Developing the capacity to apply scientific knowledge and skills is often seen as a crucial component of scientific literacy (Robert, 2011). This is because students are expected to use scientific thinking to support the decisions and actions that they take in their everyday life and in addressing real-world problems. However, many of the decisions that students make are heavily influenced by the personal, cultural, political, and social values that they have internalized (Lee & Brown, 2018; Sjöström et al., 2017). These values play a significant role in guiding personal and social practices and should thus not be neglected in the learning process (Lee & Brown, 2018).

This principle emphasizes the need to guide and facilitate opportunities for students to put into action the socio-cultural and -political values and practices that they learn in relation to SSI (Sjöström et al., 2017; Siribunnam et al., 2019). Practicing how to use or understand the role of values and practices in decision making, argumentation, and problem solving helps highlight the connections multiple disciplines have to the world that students live in (Kumarassamy & Koh, 2019). This principle is targeted by the enacted stage in the 6E inquiry model, where teachers need to promote opportunities for learners to practice how to use socio-cultural and -political values and practices alongside their moral and ethical understanding to make decisions about real science-related societal problems (Sjöström et al., 2017; Sjöström & Eilks, 2018). These types of opportunities can be used to move students beyond the classroom context to become socio-cultural and -political participants with real, complex, and active agendas. This in turn gives students time to progress towards becoming global citizens who are willing to commit to solving problems within their lives and society (Sjöström et al., 2017).

These opportunities need to be provided in conjunction with a safe and supportive classroom environment that allows students to practice how to apply their understanding of different values and perspectives in practices or in solving problems. This can encourage students to negotiate their own core values and perspectives and determine the identity that they want to enact in their lives and society (Idris et al., 2012; Sadler, 2009). Ultimately, these experiences can generate students’ sense of empowerment and commitment to position themselves as global citizens (Lee & Brown, 2018).

3.2.2 Affective Learning
Students’ affective states have a strong influence on their cognitive and behavioral development and act as a medium between the students’ learning and their situated contexts (Chong et al., 2018; Steele & Ashworth, 2018). The affective domain is multifaceted and encompasses elements such as self-efficacy,
motivation, and attitudes (Steele & Ashworth, 2018). These elements play a significant role in determining how students engage with and create meaning from their learning experiences. This principle emphasizes the need to create learning opportunities that deeply connect learning and thinking through positive values, emotions, and attitudes (Steele & Ashworth, 2018; Macalalag et al., 2019). This involves fostering opportunities to allow students to engage with creative, authentic, and meaningful ways to explore science (Harker-Schuch & Bugge-Henriksen, 2013).

Teachers can foster these opportunities through group discussions about different perspectives, contextualizing science in real-world scenarios, and hands-on activities (Kim & Chae, 2016). However, many SSI topics often challenge students’ personal, ethical, and moral values and thus elicit strong and overwhelming emotional responses (Gao et al., 2019). As a result, it is also important that teachers help students understand the role of their emotional experiences and how to navigate those experiences and develop emotional competencies such as empathy (Gao et al., 2019). Fostering emotional self-regulation helps students to understand how emotions affect their reasoning and decision making as well as their character and identity development (Davis & Belloccchi, 2017; Gao et al., 2019).

3.2.3 Authentic Context and Activities
To prepare students for the real world, it is important that they are provided with authentic contexts and activities (Herrington & Oliver, 2000). Authentic contexts and activities help to create a bridge between students’ experiences inside and outside the classroom and thus make learning more meaningful and powerful (Herrington & Oliver, 2000). This principle emphasizes the need to use instructional content that contextually and authentically situates students with real-world problems and tasks (Harker-Schuch & Bugge-Henriksen, 2013; Herro et al., 2019; Zeidler, 2016). Authentic contexts are scenarios that reflect the way that knowledge, values, and skills are used in real life (Prins et al., 2016). However, it is important that science learning is contextualized through real-world scenarios that have socio-cultural relevance (Treacy & O’Donoghue, 2014). Real-world scenarios that have socio-cultural connections are more likely to pique student curiosity and interest in a way that motivates deeper engagement (Herrington & Oliver, 2000).

Alongside authentic contexts, there need to be authentic tasks that engage students with practical activities and thinking processes (Herrington & Olive, 2000). These activities must offer a degree of uncertainty and lack of definition to reflect the real world and thus build students’ ability to navigate the complexities of the world they live in (Presley et al., 2013). Teachers will need
to ensure that students can engage with a diverse range of authentic tasks. This can include learning opportunities for students to take on multiple roles and perspectives, engage in reflection and collaboration, do research, interact with experts, and take on technology-facilitated tasks (Herrington & Oliver, 2000; Treacy & O’Donoghue, 2014). In the science context, the activities should simulate the processes, content, tool interactions, and difficulties that real scientists may face (Pérez-Sanagustín et al., 2015). However, it is important that these elements are connected cohesively and logically so that students can clearly understand their relevance (Prins et al., 2016).

3.2.4 Interdisciplinary Thinking and Integrated Practices
This key principle emphasizes that students need to be provided with opportunities to deeply discuss and apply interdisciplinary thinking and integrated practices (Herro et al., 2019; Sjöström & Eilks, 2018). Interdisciplinary thinking is a skill that involves being able to consider and apply perspectives from multiple disciplines when problem solving (Psycharis, 2018), while integrated practices refers to the ability to draw on skills that are informed by multiple disciplines and apply them to new experiences. For example, students may use their information and communication technology skills to gather data about carbon emissions. Nurturing these abilities is important because most real-world problems draw on knowledge, values, and practices from various disciplines and thus need to be addressed in a more integrated manner. By fostering students’ capacity to make and draw on connections between different concepts, the program helps them to understand how complex and multi-layered these real-world issues are and their relevance to their daily lives (Bati et al., 2018; Jeong & Kim, 2015).

These learning experiences can afford opportunities for students to develop higher-level abilities such as creativity and divergent thinking (Henriksen et al., 2019). This will enable students to transfer their knowledge and skills to other real-life contexts such as the professional workplace (Bertrand & Namukasa, 2020). In the science context, however, the program links learning to socio-cultural and -political perspectives and values, helping students to connect emotionally with the science content (Macalalag et al., 2019). This has been found to encourage greater motivation and interest and help students build a strong character for engaging in social action (Henriksen et al., 2019).

3.2.5 Educational Pedagogical Approaches
This outer layer of the model represents the educational pedagogical approaches that are emphasized in SSI-based STEAM learning. This dimension emphasizes that teachers need to implement practices that encourage
learners’ engagement and learning more effectively when they are exposed to social constructivist learning, situated learning, and inquiry-based learning. Social constructivist learning focuses on providing opportunities for students to socially and culturally collaborate and interact with others to help build their knowledge (Walker & Shore, 2015; Vygotsky, 1978). Active interactions with other students, teachers, community members, and experts help students to assign meaning to their experiences and reality and thus extend their understanding (Alt, 2018; Schreiber & Valle, 2013).

However, the learning process needs to be situated in authentic contexts and activities. This situated learning ensures that students learn from the social, cultural, and emotional experiences that are specific to their context (Brown et al., 1989). Activities can include collaboration, modelling, and reflection, which should be done in a space that encourages students to share their experiences, interests, and concerns (Pérez-Sanagustín et al., 2015). This can help students to broaden their values and perspectives and appreciate the differences between individuals and cultures (Walker & Shore, 2015). At a higher level, this nurtures students’ ability to be objective in their decision making and helps to develop stronger characters and identities (Davis & Bellocci, 2017; Sadler, 2009).

To exploit students’ natural interest and curiosity about the world they live in, inquiry-based learning has frequently been emphasized in SSI-based STEAM learning (Gillies & Rafer, 2020). Strategies used to reflect inquiry-based learning are the same as those emphasized in social constructivist and situated learning. However, in the science context the aim is to immerse students in real processes: thinking and practices that are employed by scientists such as observing and questioning (Pedaste et al., 2015). Furthermore, SSI-based STEAM learning promotes engagement with metacognitive processes such as critical and reflective thinking (Bell et al., 2013). This allows students to see the purpose behind their learning and hence emphasizes components of cognitive, social, and emotional learning (Quigley et al., 2020).

4 The 6E Inquiry Model and the Program

To translate the approach into program development, it was determined that using the traditional 5E model was not sufficient in planning and organizing opportunities for students to put into action the values and practices they learn about. This led to the creation of a 6E model, which extends the 5E model by adding an additional stage known as “enact” (Figure 4).
The aim of the enact stage is to facilitate meaningful discourse and hands-on activities to help students understand how socio-cultural values can have an impact on social practices (Clement, 2012). Learning experiences such as group discussions, role playing, and debating afford students the chance to put into action the values and practices that they explore in the classroom. These learning opportunities are framed to allow students to present their solutions for solving real-world problems to real stakeholders and experts such as the local council and school committees, and at conferences and international policy summits. Teachers need to support and guide students to make decisions based on socio-cultural values and perspectives in conjunction with their science and other interdisciplinary knowledge.

This also provides a powerful context for students to understand how their own emotions, identities, and values can influence their real decisions and reasoning (Lee & Brown, 2018). Students are enabled to perceive that their actions

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**Figure 4** The cyclic process of the 6E inquiry model. Adapted and modified from “The BSCS 5E Instructional Model: Origins and Effectiveness” BYBEE ET AL., 2006, P. 33
and decisions have foreseeable consequences and effects; thus, these experiences are more likely to encourage students to be empowered and active in building their own sense of responsibility and global citizenship.

Using the 6E model, the study developed a climate change program for Years 9 and 10. This program consisted of 11 lessons, which were organized to address six key content items related to climate change learning (see Table 3).

**Table 3** The learning content of the climate change program for Years 9 and 10

| Lesson | Content                      | Description                                                                 | Purpose                                                                                       | Example of student activities                      |
|--------|------------------------------|-----------------------------------------------------------------------------|------------------------------------------------------------------------------------------------|--------------------------------------------------|
| 1      | Personal experiences        | This content focuses on connecting climate change to students’ own ideas and experiences. | To generate curiosity and interest through relevance and emotions.                             | Students engage in class discussions about experiences. |
| 2      | Intercultural understanding | This content focuses on exploring and connecting students’ knowledge and perspectives about climate with other cultures. | To engage students with different cultures to develop connections, cultural understanding, appreciation, and mutual respect. | Group discussion with students from different cultures. |
| Lesson | Content | Description | Purpose | Example of student activities |
|--------|---------|-------------|---------|-------------------------------|
| 3–5    | Causes of climate change | This content focuses on giving students opportunities to explore scientific explanations of, and social contributions to climate change. | To promote active learning through hands-on activities. | Students collaboratively build a greenhouse to investigate the greenhouse effect. |
| 6      | Global systems | This content focuses on connecting students’ ideas of climate change to the Earth’s global systems (biosphere, lithosphere, hydrosphere, and atmosphere). | To introduce students to the science themes of climate change. | Students conduct a role play on the carbon cycle. |

**Elaborate**

| 7–9    | Impact of climate change | This content focuses on expanding further on global data trends and connecting them to the socio-cultural dimensions related to climate change. | To provide a context for students to apply their knowledge and skills to real-life contexts and develop higher order skills such as argumentation. | Students create a poster about the impact of climate change in different countries. |
Various pre-existing materials and resources were used to create this program and demonstrate that the approach can be used by teachers to help them select appropriate material. For example, the ecological footprint calculator from the World Wildlife Fund for Nature (2018) was used in Lesson 2 to help facilitate discussions among students regarding their personal carbon emissions. The six key learning areas addressed were (1) personal experiences, (2) intercultural understanding, (3) global systems, (4) causes of climate change, (5) impacts of climate change, and (6) action learning. The program was evaluated using a program evaluation tool to ensure that it adequately represented each dimension and key principle of the approach (Appendix). It must be noted that Lessons 10 and 11 in action learning contain a series of activities that engage students simultaneously in the processes of evaluation and enacting; hence, both stages are combined (as shown in Table 3).

**4.1 Benefits of the Program**

This climate change program allows students to explore a complex and relevant real-world problem that is situated in their own socio-cultural context and has connections to various disciplines (Presley et al., 2013). The program has not been implemented in the classroom, but the results from the evaluation rubric provide a clear indication of the beneficial impacts of this program.
on students’ learning. First, students are given many opportunities to practice higher-order skills such as argumentation, reasoning, and formal and informal decision making (Choi et al., 2021; Presley et al., 2013).

Second, the program emphasizes the development of emotional competencies such as empathy by providing safe spaces for students to negotiate values and enact and explore different identities (Gao et al., 2019; Sadler, 2009). For example, the program could be used to foster intercultural learning and discussion between two different cultural groups. The program enables students to understand the effects of a scientific event and how it may be perceived by people in different cultures. This can expand students’ awareness of themselves in relation to others, which is important for developing empathy. Developing this kind of emotional competency in students is important because students will need to explore ethical and moral dimensions that can elicit strong emotional responses (Gao et al., 2019).

Last, students engage with inquiry-based learning strategies that help guide them towards the capacity for putting into action the knowledge, values, and practices that they have learned in class (Tytler & Osborne, 2012). Fostering opportunities that position students to actively enact the values and practices as a medium for developing solutions is more likely to empower them with a sense of social responsibility and global citizenship. These learning experiences build on each other to enhance students’ learning in science and scientific literacy.

4.2 Limitations of the Program

The evaluation rubric also reveals that the program does have certain limitations. A major weakness of the program relates to its inability to strongly address the principle of interdisciplinary thinking and integrated practices. This results from the weak utilization of arts disciplines to generate interest and motivation and a lack of emphasis on engineering design and practices. This in turn has an impact on the ability of the program to afford students the opportunity to use integrated learning in their development of new ideas.

5 Conclusion and Discussion

This paper has set forth an approach that guides SSI-based STEAM teaching and program development. An important part of achieving this goal involved determining the shortcomings of SSI and STEAM as individual approaches.
SSI is a powerful approach in contextualizing science with relevant and meaningful real-world issues and providing students with a context to engage in discourse and explore different identities, values, and perspectives (Sadler, 2009). This has been found to promote meaningful emotional experiences and empower students to enact socio-cultural issues that they encounter in their daily lives (Gao et al., 2019; Macalalag et al., 2019). However, in reality many teachers experience difficulties in using inquiry-based strategies that involve teacher-student interactions designed to empower students in their learning (Bossér et al., 2015). STEAM, however, strongly emphasizes the utilization of student-centered strategies such as hands-on tasks and collaborative discussions. This helps to create a learning environment that encourages students to exercise their sense of curiosity and imagination while building higher-order skills, positive attitudes, and knowledge (Connor et al., 2015; Radziwill et al., 2015). However, STEAM struggles to utilize real-world problems that can authentically connect to students’ social and cultural contexts (Harker-Schuch & Bugge-Henriksen, 2013). This has an impact on students’ motivation to engage in social action and on the development of their knowledge, attitudes, and skills (Hadinugrahaningsih et al., 2017).

The shortcomings of each individual approach can be filled by integrating SSI and STEAM. This approach illustrates that SSI and STEAM can be cohesively brought together by focusing on the overlapping three dimensions and the four embedded key principles. Providing teachers with these types of teaching tools will enable them to better organize and emphasize connected learning experiences. However, to adequately address the values and practices inherent in both SSI and STEAM, the 5E model needs to be revised. By adding “enact” to the 5E model as its sixth stage, teachers will receive more direction on how to link scientific practices to students’ identities and sense of global citizenship. This can create better opportunities to foster intercultural learning between students of different countries. For example, using this program to engage students in Korea and Australia in intercultural interactions could help students to extend their understanding and perspective of real-world problems on a more global scale. Intercultural interaction can also promote the acquisition of either culturally specific or universal values, knowledge, and skills, which can in turn support their appreciation and understanding of other cultures (Lane, 2012). Both the approach and the 6E model present a new perspective on creating curricula and programs that can change how students perceive the role of science in their world and thus empower them to be agents of change.
6 Implications and Future Research

The model has numerous implications for teachers who want to use an SSI-based STEAM approach to enhance students’ relationship with science and also their scientific literacy. These implications include: (a) promoting professional teacher development to help improve teachers’ instructional delivery, (b) helping teachers understand how to align SSI-based STEAM-related practices to their curriculum and translate them into program development, (c) supporting teachers with implementation by providing educational tools and guidance, (d) supporting teachers to select and gather appropriate resources, and (e) helping teachers to create authentic learning contexts that promote intercultural partnerships and experiences for students to enhance their intercultural learning.

The program was evaluated using an evaluation rubric developed to measure how effectively the program aligned with the key principles of the approach. Using the criteria set in the rubric, the program was given a mean score for different categories, and an overall score was calculated. This allowed the strengths and weaknesses of the program to be clearly identified based on whether the program scored high or low in the different categories. For example, the program struggled to adequately address the principle of interdisciplinary thinking and integrated practices due to the limited incorporation of learning opportunities such as engineering design and practice.

Using a multi-phase development process, the study was about creating an approach and program. However, due to COVID-19 restrictions, the approach and program could not be implemented in the classroom. This raises questions about how easily the approach and program can be applied in the classroom, and whether these artifacts can be used across K-12 settings. To ensure the developed approach and programs have practical implications for the classroom, future studies will need to employ the DBR method. The next step in this research is to explore how the approach, instruction model, program, and evaluation tool would work in the classroom setting. This would help gather insights into how various class factors and teaching experiences affect the use and implementation of these teaching tools. It would also assist in refining these teaching tools to be more suitable for use by all teachers with different experience levels and across different contexts.
Abbreviations

OECD  Organization for Economic Cooperation and Development
PISA  Programme for International Student Assessment
SSI  Socio-scientific issues
STEAM  Science, technology, engineering arts and mathematics

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## Appendix

### Sample of the Evaluation Rubric and SSI-STEAM principles

| Evaluation category (total number of items) | Example of item statement | SSI-STEAM principles |
|---------------------------------------------|----------------------------|----------------------|
| Learning outcomes (5)                      | The program targets the development of students’ understanding of scientific concepts. |                       |
| Engage (6)                                  | The topic/concept/question is connected to real-world examples that generate students’ interest and curiosity. | ✓ ✓                  |
| Explore (6)                                 | The lesson(s) allow students to explore the concepts through tasks such as research and hands-on experiences. | ✓                  |
| Explain (5)                                 | The lesson(s) allow students to share what they have learned in the explore phase. | ✓                  |
(cont.)

| Evaluation category (total number of items) | Example of item statement                                                                 | SSI-STEAM principles |
|---------------------------------------------|------------------------------------------------------------------------------------------------|----------------------|
| Evaluate (3)                                | The lesson(s) provide students with opportunities to assess their own explanations against accurate explanations. | ✓                    |
| Enact (6)                                   | The lesson(s) facilitate opportunities for students to actively participate in developing local and global solutions. | ✓ ✓ ✓                |

* Note: The ticks in the table above indicate what each evaluation category targets in terms of the ssi-based STEAM principles.