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Teaching socio-scientific issues through integrated STEM education: an effective practical averment from Indonesian science lessons

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ABSTRACT

This study aims to test the effectiveness of a socio-scientific issue (SSI) based instruction through STEM-6E (engage, explore, explain, engineer, enrich, and evaluate). Controversial science topics (e.g. genetically modified organisms) in many countries, especially Indonesia, can be approached via integrated STEM education. One hundred and nine junior-high-school students from two different schools were involved in this study. Qualitative and quantitative data analyses were used to interpret the data obtained. Furthermore, a multi-level assessment framework (proximal and distal assessment) was employed in the quantitative analysis. The study results revealed that socio-scientific issue-based instruction by STEM-6E can probe a unique natural classroom interaction initiated by the teacher. The results also showed that both proximal and distal assessment had significant pre-test and post-test score differences (t-test value: proximal = −14.89; distal = −8.92). Practical significance from Cohen's d in the two assessments also showed a large effect (distal: d = 0.85; proximal: d = 1.42). The students' perceptions of this curriculum intervention, are extensively discussed. In conclusion, this current study's results support the claim that STEM-SSI can foster students' understanding, performance, motivation, and self-awareness in learning science. Furthermore, such findings contribute to science teachers in planning, processing, and evaluating classroom learning via controversial science topics through integrated STEM education.

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Science learning; integrated STEM education; socio-scientific issue; learning effectiveness; student's perception

Introduction

Socio-scientific issues (SSI) based instruction remains in line with developments in the modern era. Learning with SSI has excellent potential to cultivate student inquiry skills, especially in linking science concepts and real-world problems (Sadler, 2009). Likewise, SSI is believed to strengthen conceptual knowledge and increase student motivation in learning science (Sadler et al., 2016). Learning through SSI also provides excellent opportunities for students to hone ability, critical thinking, creative thinking, multi-

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perspective thinking, and decision-making (Ratcliffe, 1997; Wu & Tsai, 2007). Therefore, it is not surprising that many studies have tried to explore the effectiveness and investigate in-depth the SSI topic in several ways, including integrating SSI with integrated STEM (science, technology, engineering, mathematics) education. Nevertheless, the clear insight of integrating SSI with integrated STEM education in a strict country such as Indonesia, especially in terms of STEM areas on controversial topics (e.g. genetically modified organisms), is still lacking.

Moreover, SSI and integrated STEM education are compatible, as well as complimentary. SSI prepares a forum for students to practice facing real-world problems (Sadler, 2009). Furthermore, SSI becomes a training context for students to develop their abilities in preparing themselves to be actively involved in society. The great idea of SSI, perhaps, will be more valuable if utilised with an approach based on real-world problems (Martín-Páez et al., 2019). Integrated STEM education that emphasises conceptual understanding, critical thinking, creative thinking, and collaborative learning (Wahono et al., 2020) is in line with SSI's learning's main objectives. However, other benefits possessed by integrated STEM education, for instance, integrated STEM with 6E model, make learning more comprehensive, directed, purposeful, and further strengthen the role of T (technology) and E (engineering) of STEM (Chung et al., 2018). Therefore, based on the prior research, including integrated STEM education in science learning is potentially productive for teaching SSI. Potentially, the integration of SSI and integrated STEM-6E in learning instruction strengthen one another. Indeed, integrated STEM instruction that leverages SSIs can strengthen conceptual knowledge. Therefore, a high probability that instructions desired learning's effectiveness can be easily achieved would be unveiled from the integration.

Limited studies have combined SSI and integrated STEM education, particularly in terms of learning effectiveness. However, a recent study (Bozkurt et al., 2018) has examined senior pre-service teachers' theoretical and practical courses on integrated STEM education and socio-scientific issues. This research found an interesting fact to explore further, where the researchers recommended using SSI's problem situation in applying integrated STEM education. This study reveals that SSI can be an appropriate context for the practice of integrated STEM education. Other studies showing the relationship between SSI and STEM state that morals (another form of SSI) are considerations for advancing integrated STEM education (Kahn, 2015). This study reinforces the basic foundation in integrating STEM and SSI in instruction.

Furthermore, Zeidler (2016) argues that a socio-cultural perspective framed through socio-scientific considerations is offered as an alternative conceptualisation and a surplus model to hegemonic STEM education. Thus, those studies indicate high-potential effectiveness for integrating integrated STEM practice and SSI in culturally embraced instruction. It is crucial to in-depth revealing integration in such a particular context. Moreover, gaining perception from the culturally embraced students after the intervention is paramount. The result of studies has significantly contributed to enriching the body knowledge of SSI and STEM education.

The authors assume that many advantages and 'unique things' can be revealed from this current study, especially in Asian countries such as Indonesia, where many science and technology topics appear controversial (Subiantoro, 2017). The benefits can be from the discourses, the learning effectiveness, and the students' perceptions.

For instance, discourse and students' perception mostly talk about awareness and concern regarding their traditional belief in God. Tightly embracing the culture and religion renders Indonesia a profitable vessel in studying integrated STEM education by the SSI topic.

Three research questions that are the main focus of this research are:

1) What are the discourses of SSI-based instruction by the integrated STEM-6E special course of a genetically modified organism, and how do they occur?
2) Is SSI based-instruction by the integrated STEM-6E special course effective in terms of students' learning outcomes?
3) What are students' perceptions regarding teaching and learning on the SSI-based instruction by integrated STEM-6E special course?

Learning science by socio-scientific issue approach

Over the last few decades, the rapid development of science and technology has made socio-scientific issues (SSI) a challenging topic. Socio-scientific issues are complex social issues that involve concepts, procedures, and or technology and are closely related to science and its derivatives (Sadler et al., 2016). In the last decade, science education researchers have recognised the significance of SSI in engaging students in inquiries related to science and their own lived experiences (Sadler et al., 2016; Topcu et al., 2010). It cannot be denied, these facts have made SSI a crucial part of today's education world.

Furthermore, much research has revealed the advantages of SSI in learning science. Venville and Dawson (2010) stated that students taught with SSI instruction showed better learning than control classes in genetic technology-related topics. Continuing the study, Dawson and Venville (2013) argued that SSI instruction could improve students' understanding, argumentation, and informal reasoning capacities. Another study that also revealed the role of SSI in learning was conducted by Wu and Tsai (2007). The researchers claim that students in learning with SSI topics tend to process reasoning from multiple perspectives. Likewise, most of the students are prone to make evidence-based decisions.

Furthermore, a study examining teachers' perceptions of learning with SSI topics revealed that discussed SSI topics were precious for students (Byford et al., 2009). This precious value is developing an informed and enlightened citizenry and the electorate, one foundation of the discipline. Thus, SSI is a potential learning topic in creating social values and students' thinking abilities. Indeed, these instance benefits of SSI instruction give a basic groundwork to develop students' abilities in a real-world social context. Moreover, a real-world problem and social context are the best places for students to engage actively with the STEM problem. However, those studies did not fully discuss SSI's synergy and other innovative ideas in education, such as STEM. The authors assume that integration of SSI and integrated STEM education is necessary to elucidate how they provide opportunities for students to develop a number of skills.

A pivotal study developed a valuable framework concerning planning and practicing SSI and STEM (Sadler et al., 2016). The framework contains five key aspects. The five key aspects include (1) framing instruction or curriculum around a compelling issue; (2) focusing on student learning of core disciplinary ideas; (3) challenging students to collect and/or analyze data related to the issue; (4) providing opportunities for learners to negotiate social dimensions of the issue featured; and (5) using media and information and communication technologies (ICT) as means of student collection and/or dissemination of information regarding the issue. Therefore, this current research was conducted by following the five stated key aspects. The integration between the framework and the curriculum features can be seen clearly in Table 2. For instance, the framework's first aspect is 'framing instruction or curriculum around a compelling issue.' In Table 2, we selected 'the genetically modified organisms' as one of the hottest issues in the Indonesian context. Moreover, the authors put this aspect (framing instruction or curriculum around a compelling issue) in the engagement stage of the integrated STEM-6E model.

Integrated STEM education and 6E learning model

Understanding the significance of lesson enactment is becoming something essential in the world of STEM education. STEM, which is currently booming, is simply an abbreviation of science, technology, engineering, mathematics. However, STEM education is not as narrow as imagined (Li et al., 2020). STEM education can be likened to a spectrum, starting from the narrowest to the broadest understanding (Wahono & Chang, 2019). STEM's general definition is an education process in four fields: science, technology, engineering, and mathematics (Bybee, 2013). The slightly broader definition states that STEM education is an approach in teaching and learning that integrates science, technology, engineering, mathematics fields in a topic or class (Baran et al., 2016; Bybee, 2013). Other STEM education is an innovative idea in the education field to solve real-world problems, characterised by a hands-on activity that implements various disciplines or skills that hone critical thinking skills, problem-solving, and collaborative ability (Martín-Páez et al., 2019). Therefore, we prefer to use the term 'integrated STEM education' rather than STEM education in this current study context.

Thus, no exact and explicit agreement defines integrated STEM education (Li et al., 2020). However, the authors have concluded that integrated STEM education can be seen in three aspects (as well as this current study). First, integrated STEM education involves multi-disciplinary knowledge. At least two fields must be engaged in STEM learning. Second, in terms of teaching, integrated STEM can be a learning approach, specifically an integrated learning approach. Third, integrated STEM education is expected to hone any conceptual understanding, problem-solving skills, critical thinking, creative thinking, collaborative ability, and students' design thinking skill in terms of the objectives to be achieved. Therefore, integrated STEM education has become a crucial study topic and a trend, especially in the science education field.

Occasionally, in seeking better results when implementing integrated STEM education, a learning model or other approach is needed (Martín-Páez et al., 2019), such as integrating STEM education and the 6E Learning byDeSIGN ™ Model. The 6E stands for: engage, explore, explain, engineer, enrich, and evaluate. The 6E learning model modifies the previous model, namely, the 5E (engaging, exploring, explaining, elaborating, and evaluating) learning model. The 6E learning model's basic premise was to develop a student-centered model that would blend design (context and concepts) and inquiry (Chung et al., 2018). The 6E learning model is created deliberately to accommodate integrated STEM education. The researcher added an 'engineer' term to emphasise aspects of T and E in STEM and added another 'enrich' term instead of the 'elaborate' term in the 5E model (Burke, 2014). Thus, the combination of integrated STEM education and the 6E model will work together to achieve common learning objectives.

Several studies have revealed the role and effectiveness of integrated STEM education by the 6E learning model. STEM application of the 6E model in the seventh-grade student has shown better performance in terms of students' attitudes toward technology and their technical inquiry abilities (Lin et al., 2019). Another research states that implementing integrated STEM in a learning cycle of the 6E model on a direct current electricity topic improved tenth-grade students' problem-solving skills (Kaniawati & Suryadi, 2016). Likewise, a study examining the effectiveness of STEAM-6E showed that STEAM-6E learning could strengthen college students' abilities to integrate STEAM knowledge and improve their learning effectiveness in each discipline (Chung et al., 2018). The study also showed that the STEAM-6E special course for the elderly improved cooperative learning, professional knowledge, and confidence. Therefore, it is essential to further explore the effectiveness of STEM-6E in a more contextual and challenging learning framework, namely on socio-scientific issues.

Evaluation of learning effectiveness

One possible way to evaluate learning effectiveness is to look at the process or discourse in learning. Some studies identified that discourse analysis was an effective way to examine the processes that occur in learning (Aguiar et al., 2010). A framework in identifying the nature of student and teacher interaction or discourse in science classrooms has been developed. The framework was developed based on empirical analysis and socio-cultural theory (Mortimer & Scott, 2003). Furthermore, the framework is used to figure out how the teacher can help students interpret a science class learning by using different interaction patterns. Three principal focuses in the discourse analysis framework, including teaching purposes, patterns of interactions, and the communicative approach. Indeed, the teaching purpose is the main focus of the analysis conducted in this current study. The teaching purpose is a target analysis, which implies that each purpose relates to a particular phase of a lesson or sequence of lessons. Indeed, the teaching purpose analysis is significant for maintaining the lesson run and keeps on track to unveil unique and important things during the lesson.

Likewise, feedback from students after learning is crucial in evaluating student knowledge. Exploring perceptions is one of the best ways to gain feedback from the students (Little et al., 2009). Concerning STEM education, a study stated three broad students' perceptions of STEM learning in an informal setting (Roberts et al., 2018). First, *context and purpose*, this theme renders STEM learning a witness to the applicability of STEM content. In this theme, the students can recognise the importance of the STEM discipline. Likewise, this theme provides a reason for students to learn subjects like science, mathematics, or others in school, particularly for students who do not necessarily like the subject(s). Second, *opportunity and access*, this theme indicates that the students recognise access to the STEM curriculum and materials were often limited. This theme also provides students with broad and rich experiences and shows that STEM learning allows them to undergo activities they never experienced. Third, *extended content learning and student engagement*; this theme offers an enlarged expanded students' STEM content knowledge and piques their interest and engagement. This theme advances students' excitement about learning. Students' perception after the intervention is paramount in figuring out the effectiveness of teaching and learning. Therefore, gaining access to students' perceptions after a lesson gives the teachers appropriate feedback to develop well-integrated instruction in the future.

Method

Participants

One hundred and nine of 9th-grade junior-high-school students were involved in this study. Students came from two different schools, ranked to have the same quality level (BANSM, 2019). Moreover, no significant difference has been found between pre-test scores from both schools. The pre-test was both proximal and distal (The mean of school A: 37.00 and school B: 36.07). These pre-tests were collected to know the students' basic knowledge before the intervention and determine whether they have an equal background or not. The number of participants included twenty-two male students and eighty-seven female students. All the students gave their informed consent before their inclusion in the study. The schools sampled in this study were classified as suburban areas located in the capital of South Bengkulu Regency, Bengkulu Province, Indonesia. The latest version of the Indonesian curriculum for junior and senior high schools, K-13, performed as the schools' curriculum. An authentic assessment is a prevailing way to gauge and evaluate students' progress in this curriculum. Details about the participants' gender, number, and percentages are shown in table 1 below.

Two teachers taught the classes involved in this research. Both teachers have the same educational background; they have a master's degree in biology education and more than five years of science teaching experience. Furthermore, both teachers were unfamiliar with STEM in terms of teaching experience, especially integrated STEM education. However, the condition was quite different from the SSI teaching experience that both teachers had frequently thought of before. Also, before the learning process was carried out, the teachers' perception of the developed curriculum was the same.

Table 1. Participant of SSI Based Instruction through STEM-6E Special Course.

School/ Class	Category	Number	Percentage (%)
SMP1A	Male	3	12.00
	Female	22	88.00
SMP1B	Male	2	07.70
	Female	24	92.30
SMP2A	Male	7	21.87
	Female	27	78.13
SMP2B	Male	12	46.15
	Female	14	53.85

Intervention

This study is a pre-experimental design: the collective-groups pre-test-post-test, a type of quasi-experimental design. This research's main objective is to examine the curriculum's effectiveness based on socio-scientific issues through the STEM-6E special course on discourse and learning outcomes. Therefore, a framework related to planning, developing, and operating an SSI instruction (Presley et al., 2013; Sadler et al., 2016) was used in this study. The curriculum or instruction used integrated STEM learning and combined it with the 6E learning byDeSIGN™ Model. Thus, the combination was expected to provide benefits, especially concerning, solving, and facing socio-scientific issues. Furthermore, Sadler et al. (2017) have developed a great SSI teaching model and learning model. However, the model did not focus on accommodating 'engineering' in the integrated STEM hallmarks rather more focus on SSI teaching and learning characteristics.

This curriculum instruction was made to be used in science subjects in ninth-grade secondary schools. Table 2 shows the learning steps and teaching goals of the curriculum instruction. While many view genetically modified products as a promising innovation, there is controversy about their use, including inside Indonesia, an Asian country. Boccia et al. (2018) mention that the theme of genetically modified organisms (GMO) is essential for modern consumers, especially when they approach novel foods.

Three experts inspected the content design's rationality in analyzing the SSI-based-instruction's reliability and validity by the STEM-6E special course. Likewise, the experts also reviewed the objectives throughout the curriculum systematically. Moreover, the experts checked the design and assessed each question's accuracy to strengthen the questions' overall reliability and reduce errors in subsequent measurements. Two

Table 2. STEM-6E Instruction Based on Socio-scientific Issue.

Learning Steps	Curriculum Purposes*	Evaluated Goals
Engage	Raise student interest and get them personally involved in the lesson of socio-scientific issues, e.g. genetically modified organisms, while pre-assessing prior understanding.	Learners are able to recognise a dilemma as a socio-scientific issue.
Explore	Provide students with the opportunity to engage physically and mentally with the topic being studied as well as to construct their own understanding of the topic of GMOs.	Learners are able to know and are familiar with genetically modified organisms. Learners can analyze the advantages and disadvantages of GMO products.
Explain	Allow students a chance to explain and refine what they have learned so far as well as determine what the meaning of GMO and how a scientist modify organisms.	Learners are able to explain how technology can change an organism's traits.
Engineering	The step which is gives a significant opportunity for students to develop a depth of understanding about the GMO by applying concepts, practices, and attitudes. They use concepts learned about the natural world and apply them to the hand-made (designed) world.	Learners can understand the provided challenge to create a simulation model on the genetic engineering process using a pure material and under the limitation of time.
Enrich	This step provides students a more in-depth exploring what they have learned and transferring concepts of genetic modify to problems that are more complex situations.	Learners can connect the initial idea behind genetically modified organisms into other problems or issues that are facing in society.
Evaluate	Both students and teachers determine how much learning and understanding have taken place.	Learners are able to decide or have a strong argument as to whether genetic engineering is a benefit or not for society.

Note*: the curriculum purpose is the 6E learning model goal modified from Burke (2014).

senior science teachers who hold bachelor's degrees have also checked the readability and quality of curriculum instruction.

Some variations of the learning activities and contents during class were performed. The learning activities were group discussions, class discussions, questions and answers, watching movies, observing cards, and some hands-on activities such as designing DNA models and modifying DNA models into recombinant DNA. In the main discussion, the teachers used biological science and biotechnology as the foundation of student knowledge. The science concepts used in this curriculum are genetic material and biotechnology (e.g. gene, DNA, and genetic engineering technology). The main discussion topic is a socio-scientific issue, namely genetically modified organisms. Due to religious and cultural perspectives, modifying living things or part of living things are taboo activities in Indonesia. In this study, a controversial issue about GMOs was raised as an important topic of discussion. However, discussions were not only limited to the concept of science. Cultural, social, religious, economic, and political perspectives were essential ingredients of this learning process. In addition to mastering the concept of science, students also must utilise gained skills and knowledge to solve complex problems. The teachers tried to emphasise a multi-disciplinary and multi-perspective approach, especially in making decisions about and the entailed genetic modification problems facing society. Students were completely free to respond based on their beliefs and perceptions to increase the reliability of the results of experiments and minimise potential problems and sources of bias. Likewise, due to the original teacher taught during this intervention, the bias of the teaching approach newness was reduced. Indeed, the novelty of the teaching approach (SSI Based Instruction by STEM-6E) was considered a common thing by the students in the daily class activities. In addition, the instruction intervention was carried out in four different classes for a total of twenty-four hours by face-to-face interaction in four weeks.

Instruments

An idea from a multi-level assessment framework (Hickey & Pellegrino, 2005; Sadler et al., 2016) had inspired the STEM-SSI curriculum application. This assessment includes formative and summative assessments. Formative evaluation is carried out during the learning process. Instead, summative assessments are carried out using pre-test and post-test questions. Both pre-test and post-test questions comprise ten items; each test has a set of questions related to proximal assessment and a distal assessment. Those terms came from the Biology discipline. In Biology, the term distal refers to parts of the body further away from the centre. In contrast, the Proximal is the opposite of the distal. The proximal assessment contains the items closely related to the STEM-SSI curriculum's science concepts in this study. Otherwise, the distal evaluation assesses items derived from the national curriculum's general objectives in Indonesia, namely the K-2013 (The latest version of the Indonesian curriculum). Hickey and Pellegrino (2005) and Sadler et al. (2016) noticed that distal assessments could be thought of as occupying variable distances from a curriculum. The proximal assessments are embedded within instruction. These kinds of assessments likely provide critical information for teachers that can be used to inform instructional decisions. Both types of assessments focused on accessing students' science concepts. Here is an instance of the proximal question:

> Which one of the products below is a kind of biotechnology product? a) A robot, b) motor cycle, c) hybrid car, d) GMO product). An example of the distal question is as follows: The following are the main biotechnology principles, except? a) Using a genetic engineering technique, b) using a machine, c) using microorganisms, d) using chemical materials.

In the post-test section, there is also a feedback assessment. The feedback assessment was performed to assess students' perceptions after the intervention. Indeed, all the instruments have been created, developed, and modified by our curriculum development team, including distal and proximal assessment, which was made initially in English then translated into Indonesian. Those on the research and development team were experts in the field of science education and communication science. A psychometrician reviewed the instrument, as well as provided suggestions for improving face and content validity. Eventually, the reviewer's feedback was mainly used to refine the curriculum and those instruments. Moreover, to facilitate collecting the formative assessment data and analysis results, an online platform called the Cloud Classroom (CCR) was used. By using the CCR online platform, teachers could access students in real-time.

Data analysis

Statistical analysis of the paired samples t-test with a significance level of 95% through a JASP version of 0.11.1 was used for both proximal and distal assessments. The analysis was conducted to evaluate the pre-test and post-test results before and after the STEM-SSI intervention. Moreover, a sample size-independent measuring of gains on a scale of standard deviations, *Cohen's d*, was performed through the JASP as a measure of practical significance. In terms of student perceptions, the authors used a situative lens framework from Roberts et al. (2018). These themes include (1) context and purpose, (2) opportunity and access, (3) extended content learning, and student engagement. All transcripts of student responses from the feedback assessment document were categorised into all three themes. Moreover, the authors also referred to the grounded theory to analyze the data, namely adding another theme based on the obtained data. Likewise, another qualitative analysis was carried out to evaluate the STEM-6E special course implementation's discourse progress by analyzing documents. The documents included written transcripts, which were transformed from tape recorders and data in the formative assessment on the CCR platform. Indeed, this discourse analysis investigates language and the meanings given to texts that create and shape knowledge and behaviour. The discourse analysis primarily focused on class discourses fitness to each sequence (6E model) of lessons teaching purposes. The students' responses to the teachers driving questions are comprehensively depicted by about 85% because teachers ask not all students during the class. A coding system assisted the data analysis that the authors have developed. For example, code SA04, means the opinion or statement of 'S = student' class 'A' with '04=text/ information number 4.'

Results

The results presented below focus on answering the three research questions that have been raised. First, a qualitative analysis describes the discourses of SSI based on instruction by the STEM-6E special course of a genetically modified organism and how do they occur in teaching and learning. Second, SSI's effectiveness based on instruction by the STEM-6E special course regarding student learning outcomes, especially in the proximal and distal assessment, is discussed. Finally, the students' perception regarding teaching and learning through the SSI-based instruction by STEM-6E special course is presented.

Learning discourses of SSI based-instruction by the STEM-6e

In describing the processes that occur during learning, a step-by-step format of the 6E learning model is utilised as a guide. The 6E learning model is comprised of specific steps, namely engage, explore, explain engineering, enrich, and evaluate. The discourse mainly focused on each sequence of lessons teaching purposes (a selected principal in the discourse analysis framework).

Engage stage

Engagement is the first step and one of the essential stages in a learning and teaching process, particularly in this study. This stage is one of the critical factors for students in preparing mentally and physically facing the lesson. Therefore, the teachers tried to link the prior knowledge of students with the current learning topic. The teachers displayed videos such as the X-Men movie trailer, an image of the world, and various fruits (food) to attract students' attention while linking their fundamental knowledge to the subject matter. A student, SB02, stated, '*The video or film trailer shown depicts an interesting event, where a human being was injected with something to be modified according to the wishes of the person who injected it.*' The opinion indicated that the student had been successfully motivated into the lesson topic, modifying organisms. Another opinion, SC03,

> The images and questions displayed are enough to make me think hard. The displayed images, questions, and choices by the teacher seem to have advantages and disadvantages of each; if I choose one answer, let's say I will select food that I can choose by myself from the one given by God; of course, this question is very tricky, and will be a long discussion.

The opinion of SC03 illustrates that the teacher has indirectly tried to convey regarding the lesson, which contains a complex socio-scientific issue. The teacher has endeavoured to link the topic's content with one of the learning objectives, namely, to discuss the product of genetically modified organisms (GMO) as one of the controversial topics.

Explore stage

At this second stage, students get an opportunity to be involved both physically and mentally with the lesson topic. The teacher gave several types of GMO cards to be observed by students. A student, SC08, mentions,

> Observing the GMO cards provided by the teacher lets me know more and give me a direct experienced some keywords on the GMO products. Previously, I was completely unaware of

> the labeling or information about genetic engineering products in several types of food sold on the market.

Furthermore, to strengthen the explore stage, the teacher also displayed a video about the pros and cons of GMO products. The video was shown to broaden students' perspectives and students' mental involvement in the discussed topic. A quite similar situation is also shown by SB11's opinion, '*To be honest, I became even more confused about the controversy presented by GMOs. Both parties (pros and cons) would seem to make statements as if everything were true. They have the same strong opinion.*' Those discourses verified the success of the teacher concerning involving students' minds with the lesson.

Explain stage

The explanation step provides an opportunity for students to communicate what students have learned so far. In this third step, the teacher gave a guiding question '*how can technology change or modify an organism?*' This question provoked students to explain and communicate with each other, clarifying what they know, and do not know, so far. SD02, '*I think, by advances in technology, scientists can modify other living things, especially through changes in genetic material inside the body of the organism.*' Besides, the teacher also tried to grasp student understanding through some direct answers from the students. Therefore, the lesson purpose of the *explain* step is confirmed.

Engineer stage

This fourth stage allows students to understand the topic problem more in-depth, involving various practices, concepts, and attitudes. The teacher has designed two challenges that must be solved by students. The first challenge was that the students in their groups were assigned to design a pair of DNA strand models from various provided materials and equipment (figure 1). Students were given a free opportunity to design and select the materials and tools that would be used to deal with the challenge. SA15,

> When the teacher gave the challenge, we tried to understand what the teacher wanted. However, when we saw so many tools and materials available, my friends and I were confused. We tried to select and sort out the materials that were needed, and then we tried to design the DNA models.

At this stage, a hands-on activity and students' science concepts are honed. Engineering and technology skills are needed. Mathematical thinking is required, especially in the decision-making process.

In the second challenge, the teacher asked students to modify or combine the two DNA strand models that have been made into a recombinant DNA strand. The students must observe which part of the strand must be cut off and why that part must be cut off. SD06, '*To be honest, my friends and I must re-open any note in our book and re-understand the concept of recombinant DNA.*' A science concept, especially about the restriction enzymes, ligase enzymes, and cutting points of DNA, becomes the main science concept known by the students at this stage.

Figure 1. Materials and equipment, as well as students', work.

Enrich stage

This fifth stage allows students to explore the conceptual understanding further and apply it to other different situations. In this SSI by STEM-6E learning, especially at this enrichment stage, the teacher asked students to guide students using their existing knowledge and understanding of other conditions. The teacher asks,

> To respond to the rapid population growth and climate-change effect as well as an uncertainty condition in the world, please provide a simple idea to do, besides genetic engineering, especially in terms of food availability and the survival of human beings!

One student's response, SD09,

> I think; besides GMO technology, we can return to plant breeding techniques, which crossbreed one superior trait with another excellent trait. However, we can do it differently. For example, using more sophisticated technology in the breeding can accelerate and provide greater opportunities for getting better results.

The student response shows that they are trying to go beyond the main topic's instructions (GMO) as a hint of thriving in the enrichment stage.

Evaluate stage

This last stage is carried out as an effort to determine the extent of the learning process. The teacher also emphasised essential points that students must understand, especially on the controversial topic of learning, as it was. At this stage, the teacher also gave a closing statement, namely,

> as a student or a member of society; we must always think critically about everything, must constantly think from various aspects or points of view; we must consistently try to find evidence in arguing, and finally in decision making, we can return to an own personal belief.

Also, the teacher evaluated the student's final view of genetic engineering in an organism. One student argued, SD18, '*I agree with the genetic engineering due to the welfare and survival of living things is very important*.' However, another opinion that gives the teacher information about student positions is SD24,

> I have not been able to put where my position is. All the positions have both advantages and disadvantages. As a layperson, I will say that GMO products are beneficial and promising. As a spiritual human being, I somewhat disagree about modifying the organism, which is only for fulfilling momentary human interests, and also because of the risk of other negative impacts.

The authors can conclude that students' decision-making process, especially on complex problems, is not uniform and easy to solve at such students' responses. However, those discourses indicate that the teacher has succeeded in determining how much learning and understanding have occurred.

Impact on academic learning achievement

The second research question that will be addressed in this study is about the effectiveness of SSI Based Instruction by the STEM-6E special course of a genetically modified organism. The interventions carried out on the ninth-grade junior-high-school students were gauged through a multi-level assessment (table 3). Besides assessing each class, the author also analyzed all four classes simultaneously as a whole variable. The t-test score and effect size are the leading indicators in this effectiveness assessment.

The results in table 3 indicate that SSI Based Instruction by STEM-6E is significant in improving students' academic learning achievement. The improvement shows on both the proximal assessment and distal assessment in all classes. The proximal assessment, an assessment of students' knowledge related to the science concepts in the instruction developed, shows a t-test score of −14.89. This score means a significant difference between pre-test scores and the post-test score of students' proximal assessment.

Table 3. Multi-level Assessment Result of SSI Based Instruction by STEM-6E.

Classes	Assessments	N	Pre-test mean	SD	Post-test mean	SD	t	Cohen's *d*
A	Proximal	25	34.40	13.56	80.80	16.81	9.56*	1.90
	Distal		42.40	20.26	64.00	16.33	4.30*	0.86
B	Proximal	26	38.46	16.89	68.46	18.90	7.72*	1.51
	Distal		33.07	22.58	63.84	16.98	5.75*	1.12
C	Proximal	32	36.87	21.01	68.75	21.51	5.84*	1.03
	Distal		35.62	24.74	65.62	18.48	5.56*	0.98
D	Proximal	26	33.07	15.92	73.84	18.56	8.78*	1.72
	Distal		38.46	21.85	53.07	21.12	2.51*	0.49
ABCD	Proximal	109	35.78	17.22	72.66	19.56	14.89*	1.42
	Distal		37.24	22.52	61.83	18.76	8.92*	0.85

*$p < .05$.

Whereas, distal assessment, an assessment of students' understanding that is not directly related to what is inside the developed instruction but relates to a more general theme in the national curriculum, shows a t-test score of −8.92. The score means a significant difference between students' pre-test and post-test of distal assessment scores. Thus, SSI Based Instruction by STEM-6E effectively increases academic learning achievement in the case of hereditary material and genetically modified organisms. Furthermore, the instruction was also effective in improving academic learning achievement, which is more broadly related to the national curriculum themes, especially about the DNA concept in general and Biotechnology applications in society.

Likewise, Table 3 shows the effect size of each class and the overall effect size, which indicates a large effect of the application of SSI Based Instruction by STEM-6E. Overall, the proximal assessment's effect size score from 109 students is 1.42, while the distal assessment's effect size score is 0.85. The result means there is a difference in the effect between the two assessments, where the effect on the distal assessment is smaller than the effect on the proximal assessment. However, both scores support strengthening the results shown by the t-test, which stated that SSI Based Instruction by STEM-6E effectively significantly promotes student academic achievement.

An exciting result shows differences in pre-test and post-test standard deviations between proximal assessments and distal assessments (table 3). After the intervention of the proximal assessments (19.56), the standard deviation scores are more significant than before the intervention (17.22). Conversely, the distal scores' standard deviations are smaller after the intervention (after, 18.76; before, 22.52). Furthermore, each class and the total score of the four classes simultaneously show pattern differences.

Students' perception after the intervention

Another analysis was conducted to see whether the SSI Based-instruction by the STEM-6E special course is effective and coincides with answering the third research question about analyzing students' perceptions after the lesson. A *situative* lens framework with modified themes from Roberts et al. (2018) has been used. The three themes raised by Robert et al. include *provided context and purpose*, *opportunity, access, and extended STEM content and engagement*. However, based on the data obtained, we modified the framework and added another theme: student self-awareness of the environment and daily live activity (SaEDLA). The authors think that this theme is different from those three existing ones. Authors assume that those three themes from Robert's framework focused on STEM education itself rather than STEM and SSI simultaneously instruction. The percentage of students' perceptions is shown in detail in figure 2.

Figure 2 shows that most students' opinions after the lesson are on the theme of STEM content and engagement (64.71%). The following statements are examples of student opinions related to the theme. SB22, '*I know much more about the benefits and adverse effects of using genetic engineering.*' Another instance of other students' perceptions is SC02: '*After the learning, I am delighted and hopefully could study the science course just like this situation again in the future.*' These findings reinforced the previous results in this current study that showed the SSI Based Instruction by STEM-6E was effective in increasing student academic learning. In this theme, students' perceptions were related to the science of genetic material and engineering. Besides, students

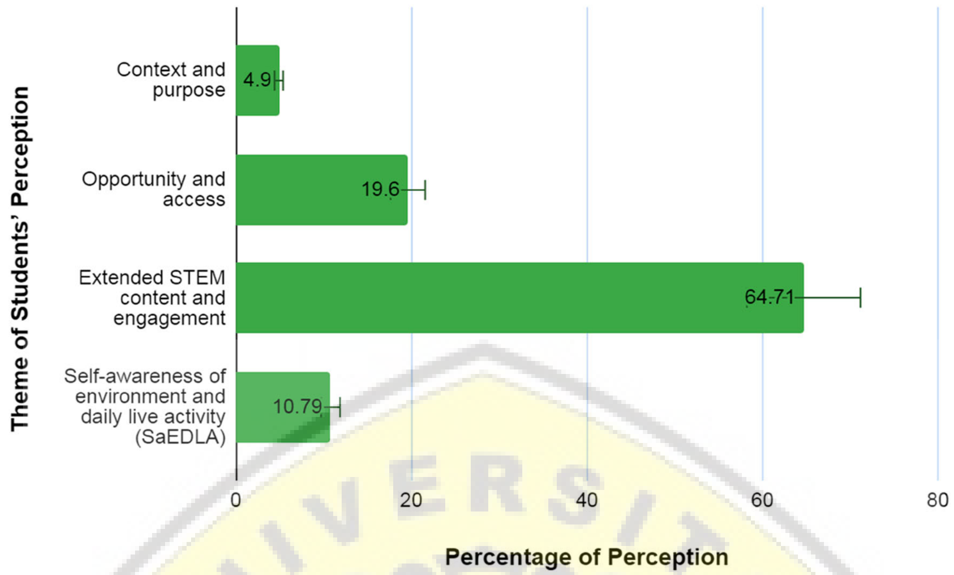

Figure 2. Student Perception of the SSI Based Instruction by STEM-6E.

found that the concept is easy to understand using this instruction or approach. Likewise, the students felt happy and want to learn science as it was happening. This perception means that students are enthusiastic about learning science with the SSI Based Instruction by the STEM-6E.

Self-awareness of the environment and daily live activity (SaEDLA) has become an interesting finding after learning throughout the SSI-Based Instruction by STEM-6E. The SaEDLA is not one of the themes promoted by Roberts et al. (2018). However, through a formal learning setting in the current SSI learning, the authors find that some of those students' perceptions could not be categorised into Robert et al. themes. The following statement is an example of a student's perception in the SaEDLA categorisation, SD08, '*I feel I am becoming more careful towards the environment. I will be cautious about buying some things and will always pay attention to the composition and labels of food products*.' In this theme, 10.79% of students feel more cautious about their health and the global environment's continuity. This awareness is mainly related to daily food choices. Students become more critical and careful not only for themselves but also for the resulting impact on the surrounding environment.

Discussion

The interrelationship of SSI and STEM-6e promotes student academic learning achievement

Academic learning achievement has been effectively obtained from the current SSI Based Instruction by STEM-6E learning. The academic learning effectiveness has proven from the significance of the t-test scores (t-test of proximal = −14.89; distal = −8.92) and the magnitude of the effect sizes both at proximal assessment ($d = 1.42$) and distal assessment

($d = 0.85$). These results are inseparable from the synergistic relationship between integrated STEM education characteristics and the 6E learning model.

As well known, the 6E learning model was deliberately created to accommodate STEM education (Burke, 2014). Each stage in the learning model (STEM-6E) has the great potential to contribute to students' academic understanding (Chung et al., 2018). In this current study, the stages, which were done linearly, greatly influenced the learning outcomes. Indeed, the process of making connections between students' initial knowledge and the lessons is seen at the *engage* stage. A good connection between the initial knowledge and the learning content is the key to achieving the lesson goal (Burke, 2014). The opportunity to be directly involved with the problems can be seen in the *explore* stage. The process of communicating what has been and has not been learned is shown at the *explain* stage. Both the *explore* and *explain* stages are crucial in enhancing the students' academic learning achievement by widely exposing content knowledge (Chung et al., 2018). The inquiry and its integration of the science concept are revealed at the *engineering* stage. Kelley and Knowles (2016) argue that science lessons can be enhanced by infusing an engineering design approach because it creates an opportunity to apply science knowledge and inquiry and provides an authentic context for learning mathematical reasoning for informed decisions during the design process. The transferred understanding of new situations or problems is found at the *enrichment* stage. Likewise, the diagnostic process is explored at the *evaluation* stage. In the end, making a combination of integrated STEM and the 6E had an outperformed effect on the students' academic learning achievement. Therefore, this result enriches the knowledge body of the STEM-6E model; the positive synergistic effects can be obtained from a conventional STEM-6E model and in integration with a socio-scientific issue instructional teaching model.

Furthermore, a provoking result exciting to discuss is that the proximal assessment score is higher than the distal assessment score. The situation indicates that the 'delivery power' of the developed instruction (SSI-Based Instruction by STEM-6E learning) was high. The reliable delivery power allows students to understand fluidly the learning concepts contained in the developed STEM-SSI instruction. Slightly different from the proximal assessment, the distal assessment, a tool to access the concept understanding derived from a broader curriculum goal, namely the national curriculum for science education, showed a somewhat smaller score. However, the score is still categorised as an effective gained. This result is in line with research from Sadler et al. (2016), who examined one of the socio-scientific issue topics, especially about identifying and treating sexually transmitted diseases. The study showed that the proximal assessment score reflects a better value than the distal assessment score. Therefore, the SSI Based Instruction by STEM-6E is powerful not only for concept understanding that is closely related to the instruction but also for broader science concepts in general.

However, another interesting fact from the study results is that the pattern pre-test and post-test standard deviation (SD) scores for proximal and distal assessments are inversely different. The SD proximal assessment score was higher after the intervention (pre-test, 17.22; post-test, 19.56). In contrast, the distal SD assessment scores are smaller after the intervention (pre-test, 22.52; post-test, 18.76). This result illustrates that the scores obtained by students in the proximal assessment are more varied than the scores obtained by students in the distal assessment. This illustration means that although the learning has a large effect on the mastery of students' concepts on science understanding, especially those related to the concept that available in developed instruction, the resulting scores are more diverse, most likely due to differences in students' academic abilities (Wahono et al., 2020). Thus, the distance score obtained between the low-ability students and the high-ability students becomes greater. In the context of learning on the SSI topic through STEM, which focuses on solving complex problems, high analytical skill is needed (Bozkurt et al., 2018). Therefore, this situation is sufficiently facilitated by students with better academic ability. However, on the assessment questions that are not tightly related to the concept in the developed instruction (on the contrary, the concept is more general and broader), the students are more comfortable adjusting based on their basic abilities.

A combination of socio-scientific issues and integrated STEM education cultivates students' self-awareness, motivation, and multi-perspective thinking

The local-style integrated STEM-based instruction, which tends to be a cultural perspective, has generated excellent student motivation and self-awareness of the environment and daily live activity (SaEDLA). High interest in learning (64.71%) shown from this study results indicates a significant motivation, indirectly impacting the instruction (Roberts et al., 2018). Hand on activities undertaken, challenging controversial questions, and technology media such as cloud classroom (CCR), are the main reasons for the students' interest. Furthermore, the students' self-awareness of the environment and daily live activity (SaEDLA) appears to be one of the new themes after the learning, strictly influenced by the socio-scientific issue instruction. Students finally realise that in their daily lives, they are inseparable from the various choices. Whether like or not, these choices will, directly and indirectly, impact themselves and the environment. Moreover, environmental awareness is one of three important areas of students' attitudes towards science in the PISA assessment framework (OECD, 2016).

Eventually, the controversial topic of genetically modified organisms has forced students to reason from various viewpoints. This assertion is indicated by the students' responses, such as at the *explore* phase, which stated that students must think hard about the best choice of some issues displayed by the teacher. This situation forces students to think from many perspectives in deciding their best choice. At the *engineering* stage, the students also claimed that they had to try hard to select the materials provided by the teacher to construct a DNA model. Moreover, the students used mathematical thinking, design thinking, and science concept to the fullest in the design process. Therefore, said empirical findings support an idea mentioning that SSI lessons through integrated STEM activity have a role in preparing students to face uncertain global world challenges (Bozkurt et al., 2018; Zeidler, 2016).

Furthermore, the teacher also played an important role in honing students' multiple-perspective thinking skills during learning. In the evaluation part of the 6E model, the teacher clearly emphasised one of the key sentences, namely, '*in dealing with socio-scientific issues, students and individual persons, in society, need to think critically as well as to see from some criteria*.' A crucial role of a teacher in honing multiple-perspective thinking is supported by the opinion of Wang et al. (2006, june 27). They stated that multiple-perspective thinking had a great potential in forming training programmes, including learning in the classroom, involving cross-culture experiments, and various media and technology. Therefore, the SSI Based Instruction by STEM-6E effectively cultivated multiple-perspective students' thinking skills.

Role of instructional properties

Outperformed results indicate that integrated STEM education needs other properties, such as learning models or learning strategies, to promote students' learning outcomes. The presence of specific learning models or learning strategies leads to achieving learning goals (Martín-Páez et al., 2019; Mustafa et al., 2016). However, it should be noted that integrated STEM learning could be implemented with or without other learning models or approaches. Learning models such as the 6E learning model can facilitate integrated STEM education to achieve instruction or curriculum effectiveness. Besides the 6E learning model, another researcher, Mustafa et al. (2016), has investigated the efficacy of project-based learning models in implementing integrated STEM education in the classroom. Therefore, the implementation of integrated STEM education will promote students' academic learning achievement on the condition that a learning model or other approaches accompany the enactment.

The effectiveness results in this current study, likewise, came from a natural science learning setting. The learning setting followed a regular class setting (three lesson hours/ per class). There was no time changing or time modification of the lesson hour on those classes. Therefore, this natural setting was also utilised to reduce the intervention's bias (e.g. Hawthorne effect). Most integrated STEM enactment is carried out in informal conditions such as in a STEM club, STEM camp, STEM project, or modified class schedule (Chen & Chang, 2018; Lou et al., 2014; Shahali et al., 2017). However, this current study proves that integrated STEM education can be effectively applied to a regular classroom setting. Extra preparation, great support from various parties, and mastering any practical application of integrated STEM education are the keys to success.

Conclusion and implications

Teaching SSI by STEM-6E special course of genetically modified organisms in Indonesia is highly effective in honing any crucial students' learning outcomes in the twenty-first century. The instruction mainly cultivates a positive classroom activity that fosters better academic learning achievement, motivation, multi-perspective thinking, and creative thinking. These findings added new insight into the field of teaching socio-scientific issues, which initially were known for their powerful effects in honing students' reasoning and argumentation skills. This finding also strengthens the evidence that integrated STEM learning increases students' motivation, creative thinking, critical thinking, and problem-solving skills and strengthens science concept understanding.

Self-awareness of the environment and daily live activity (SaEDLA) is a new theme promoting from the current study that did not find in the original framework adopted by Roberts et al. (2018). This finding is remarkable because SaEDLA is something fundamental in life and society. Self-awareness itself can be more important than the other learning outcomes. Students become more aware of who they are and what the best is for themselves and the environment. In the current crisis of the world's attention, the

SaEDLA can be valuable as a new target to be achieved in science learning, including preparing good attitudes towards science in the PISA assessment.

Some practical suggestions for teachers, especially in planning, processing, and evaluating learning by controversial science topics through integrated STEM education, are derived from this research. First, integrated STEM enactment could also run effectively during a formal classroom setting. The meaning is that the teachers do not need to worry that implementing integrated STEM education must require much time and be applied to informal learning settings. Second, combining integrated STEM education with other approaches or a learning model will have a better impact, especially to achieve the learning objectives. Finally, reflecting on the results obtained from the proximal and distal assessments in teaching topics related to socio-scientific issues, teachers must pay special attention to the students with low academic abilities.

Nevertheless, this current research also has some limitations. An imbalance participant number between male (22.02%) and female (77.98%) samples is one possibility of the limitation. The sample chosen was random, as well as in a regular class setting. Thus, a more extensive study is needed to get a perfect result, especially with larger sample sizes and the gender proportion of students nearly equal. Second, the topics of the teaching material covered are only about genetically modified organisms (GMOs). Consequently, this study only represents one of many SSI topics. Therefore, understanding how different topics will affect the process and learning outcomes' effectiveness through SSI-based instruction by the STEM-6E is another potential subject for future research.

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