EXAMINING THE RELATIONSHIPS BETWEEN SOCIO-SCIENTIFIC REASONING, CONTENT KNOWLEDGE, AND PERSONAL INTEREST

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by

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A candidate for the degree of Doctor of Philosophy,

And hereby certify that, in their opinion, it is worthy of acceptance.

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DEDICATION

To my parents for their working hard, loving me unconditionally and raising me in a very difficult situation.

Dành tặng ba má. Con biết ơn sự hy sinh thầm lặng của ba má để nuôi con nên người trong những ngày vô cùng gian khó của gia đình mình.

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EXAMINING THE RELATIONSHIPS BETWEEN SOCIO-SCIENTIFIC REASONING, CONTENT KNOWLEDGE, AND PERSONAL INTEREST

Hai T. Nguyen

ABSTRACT

Socio-Scientific Issues (SSI) appear to be a viable means for promoting students' development of science literacy, providing relevance to scientific concepts for students to apply their understandings and make sense of science-related issues. However, the question remains as to how their reasoning competencies regarding these issues interact with their content knowledge and personal interest. The purpose of this study is to explore and examine the relationships among Socio-Scientific Reasoning (SSR) competencies and between SSR and Content Knowledge and Personal Interest of students as they engage in a series of SSI. A total of one hundred and thirty students completed three sets of Quantitative Assessments of SSR (QuASSR), personal interest surveys and summative science unit tests. Correlation analysis and Structural Equation Modeling (SEM) were used to elucidate relationships between SSR and Content Knowledge and Personal Interest across three SSI scenarios. The results of the analysis revealed that students' SSR competencies varied across three different SSI scenarios. Students showed greater their SSR competencies in the Vaccinations scenario than in the Global Warming and Genetically Modified Organisms scenarios. The analysis also revealed that SSR competencies have interactions with cognitive and affective domains, in which lower-order Content Knowledge and Personal Interest have a significant impact. Particularly, the level of Personal Interest in each SSI might have a large effect on the increasing level of SSR. This study highlights that SSR is a dynamic multi-dimensional construct and influenced by Content Knowledge and Personal Interest across three different SSI contexts. These findings have implications for science teachers when they want to develop meaningful SSI scenarios to support SSR development and to integrate SSI into a science course with diverse topics. In addition, the SSR conceptual framework employed and findings in this study would be helpful for science education researchers who want to find a better way to support students' success in scientific literacy. Limitations of this study and recommendations for future research are also discussed in this dissertation.

CHAPTER 1 - INTRODUCTION

1.1 Scientific Literacy and Socio-scientific Issues

One of the aims of science education is to promote and develop scientific literacy for all students, and content knowledge is often considered a principal component (e.g., Hurd, 1998; Ryder 2001). However, in a comprehensive review, Roberts (2007) offered two broad viewpoints on scientific literacy: Vision I represents the traditional focus on the content that individuals need to know in terms of content knowledge, while Vision II emphasizes on what science learning looks like in the application of scientific knowledge. From this view of scientific literacy, one needs a firm grasp of scientific knowledge as well as the means to make use of that knowledge to reason about "real life" issues (Roberts, 2007). If people in a democratic society are expected to make informed decisions about scientific and societal issues as a part of key outcomes of scientific literacy (Abd-El-Khalick, 2003), then students should be able to elaborate both the content of learning (the what) and the process of reasoning (the how). In order to determine how students can reason about the science-related issues they experience in daily life, an evaluation of students' scientific knowledge understanding should be combined with their ability to use scientific knowledge to make decisions (Sadler & Zeidler, 2009; Roberts & ByBee, 2014). The use of contemporary and controversial issues, known as socio-scientific issues (SSI), in science education (e.g., genetically modified foods, antibiotic resistance in agriculture, vaccination, climate change), is well-supported as an effective way for promoting learning aligned with Vision II scientific literacy goals, especially engaging in scientific practices for solving problems and negotiating complex societal issues (Zeidler & Sadler, 2011; Zeidler, 2014).

1.2 Assessing learning in SSI context

Interestingly, many studies suggest that context matters for SSI (Karisan & Zeidler, 2017). Numerous studies have provided measures for assessing student learning in SSI contexts, such as content knowledge (Dori, Tal & Tsaushu, 2003), informal reasoning (Sadler, Barab & Scott, 2007; Klosterman & Sadler, 2010), attitudes toward science (Lee & Erdogan, 2007), argumentation (Dawson & Venville, 2010), decision-making (Bell & Lederman, 2003; Sakschewski et al., 2014), moral reasoning (Zeidler & Keefer, 2003), and epistemological understandings (Khishfe & Lederman, 2006). In fact, SSI-based instruction engages students in their learning through exploring socially controversial real-world issues related to the scientific content. Thus, assessing students' learning in such contexts is necessary to reveal whether students can connect science content to their own lives and how students apply their scientific knowledge. However, very few have accounted for how students' thinking develops through SSI. Recently, a construct, named socio-scientific reasoning (SSR), has been developed as an educational tool for teachers and researchers to evaluate student thinking practices as they work to resolve complex SSI (Sadler et al., 2007). Many researchers claim that SSR enables exploration of reasoning processes in SSI contexts (as opposed to simply testing concepts) and provides more adequate interpretations of the scientific information already learned in science education (Kinslow, Sadler & Nguyen, 2019; Karahan & Roehrig, 2017; Sadler et al., 2011; Simonneaux & Simonneaux; 2009).

It has been argued that SSI engages students with relevant context of societal issues influenced by scientific phenomena, in which the students apply evidence-based scientific content knowledge to resolve real-world socio-scientific scenarios (Kinslow & Sadler, 2017; Sadler, 2004, Zeidler & Sadler, 2011). In fact, there is convincing evidence to show that the use of SSI in science teaching and, in particular, the discussion of controversial issues has an effect on students' science learning. However, despite the available empirical evidence, relevant questions regarding the relationship between SSR and learning context remain. One of these questions is whether different levels of content knowledge and personal interest influence students' reasoning. I plan to conduct a study with the aim of contributing with experimental evidence gathered in classrooms to the understanding of the relationship between SSI and content knowledge learning.

1.3 Defining and explaining SSR

Socio-scientific reasoning (SSR) is a construct representing some of the cognitive demands associated with the negotiation and resolution of SSI (Sadler et al., 2007). In postulating SSR, researchers suggested four inter-related aspects: (1) *Complexity*: Identifying the intrinsic complexity of SSI; (2) *Perspective-taking*: Considering SSI from multiple perspectives; (3) *Inquiry*: Recognizing that SSI are subject to ongoing investigation; and (4) *Skepticism*: showing skepticism as inherently biased information is provided (Sadler et al., 2007). Those aspects are considered as necessary elements of reasoning that may help to negotiate controversial issues within SSI contexts. In order to elicit SSR in SSI contexts, several science education researchers have attempted to use diverse scenarios (Sadler et al., 2011; Sakschewski et al., 2014; Romine, Sadler & Kinslow, 2017). Existing studies indicate that SSR patterns are likely consistent across different scenario contexts (Sadler et al., 2011; Topcu, Sadler, & Yilmaz-Tazun, 2010; Romine et al., 2017). However, relationships between SSR and other factors related to SSI such as personal interest and content knowledge as demonstrated in different cognitive process levels are still not fully understood. Although several researchers have attempted to account for other aspects of the SSR construct in various ways (e.g. Simonneaux and Simonneaux, 2009; Eggert and Bogeholz, 2010; Morin et al., 2013), it is not fully understood how such expansions necessarily strengthen the SSR as a useful construct in terms of assessing and supporting students' reasoning in the settings of SSI interventions. Recently, Karahan & Roehrig (2017) have proposed three additional aspects for the SSR theoretical construct, including (1) identifying of social domains influencing the SSI, (2) applying cost and benefit analyses for claim determination, and (3) considering other factors associated with SSI contexts. However, these expansions seem more likely related to content knowledge and skills as working in SSI contexts rather than conceptualizing and reasoning (Romine et al., 2017). For this reason, I consider four cognitive practices (complexity, perspective-taking, inquiry, and skepticism) as the constitutive components of SSR.

1.4 Affective domain in science learning

Learning has been known as a process that integrates cognitive and affective domains (Bransford, Brown, & Cocking, 1999; Volet 1997; Littledyke, 2008; Wickman, 2006). While the cognitive domain has attracted many studies and is rather well understood, the affective domain is still less clear and more complex. For instance, researchers included many factors, such as attitude, motivation, belief, and interest in measuring the affective domain (e.g., Alsop & Watts, 2003; Simpson, Koballa, Oliver & Crawley, 1994). Although many factors may contribute to the affective domain of students' learning, their interest in learning is of particular importance when developing curriculum and instructions.

Interest is generally described as a multifaceted concept with both cognitive and affective domains (Gardner & Tamir, 1989; Hidi, 1990; Krapp & Prenzel, 2011; Renninger & Hidi, 2011; Silvia, 2006). Krapp (2002) proposed that interest is a dynamic interaction between an individual and an entity. Supporting with that idea, Schiefele (2009) argued that interest is a content-related concept because it is always attached to a certain object, subject, idea, or activity. In terms of the stability of interest in educational contexts, researchers typically divide interest into two types: personal (or individual) and situational interest. Whereas personal interest expresses a reasonably stable tendency (Azevedo, 2011; Hidi & Renninger, 2006; Krapp, 2003; Renninger, 1992; Renninger & Hidi, 2016), situational interest "describes a short-term psychological state that involves focused attention, increased cognitive functioning, persistence, enjoyment or affective involvement, and curiosity" (Schiefele, 2009, p. 198). Thus, situational interest is motivated by interesting characteristics of a particular learning situation, which is associated with the learner's attention to the object of interest (Hidi & Renninger, 2006; Schraw & Lehman, 2001, Renninger & Hidi, 2016). Situational interest also is suggested as a beginning point for long-term development of new interest in a specific domain (Krapp, 2002).

Findings from empirical research have shown the positive effect of interest on learning and suggested that interest plays as one of the most important motivational factors in learning (e.g., Renninger & Bachrach, 2015; Schiefele, 1999). For instance, interest can significantly impact academic achievement (Bybee & McCrae, 2011; Rotgans & Schmidt, 2011; Papanastasiou & Zembylas, 2004) and also enhance higher cognitive processing and students' attention (Ainley, Hidi & Berndorff, 2002; Schiefele, 1999). When students find a topic interesting, they usually show greater attention, persistence to the content and ultimately focus on deepening their understanding (Krapp, Renninger & Hidi, 2004; McDaniel et al., 2000; Renninger, 2009). Researchers propose many possible mechanisms by which interest can trigger positive emotions in a person, such as enjoyment and enthusiasm. For instance, interest in a subject has been associated with better knowledge processing (Pintrich et al., 1993; Schiefele, 1999; Tobias, 1994), more efficient working memory (Hidi & Renninger, 2006), facilitated conceptual understanding (Nieswandt, 2007), enhanced academic achievement linked to learning from text (Schiefele, 1999), improved self-efficacy (Linnenbrink & Pintrich, 2003), and better problem-solving skills (McLeod, 1992).

Given the nature of interconnection between scientific and societal perspectives, SSI scenarios challenge students' science content knowledge understanding and rationale, as well as their social and emotional perspectives

(Sadler, 2004, Sadler & Zeidler, 2004; Zeidler & Nichols; 2009). Many findings indicate that students in science classes are interested in working with problems that entail a humanistic outlook (Aikenhead, 2006; Lindahl & Lundin, 2016) or with health issues, new medical discoveries, and environmental controversies (Ratcliffe & Grace, 2003). It is often assumed that students have greater interest in the issues, they then will process information in deeper levels and actively engage in exploring the science behind the issues. In this study I chose to focus on personal interest in SSI topics for two reasons: **(1)** the personal interest (also known "individual interest") is associated with a relatively enduring psychological state of positive affect and is one of the major factors driving to motivation and learning (Hidi & Renninger, 2006; Renninger, 2009) **(2)** the measure of situational interest may be more complicated since it can be generated in particular conditions (such as in a classroom or specific activity) and may contain methodological challenges in considering all situational elements of science learning (see Linnenbrink-Garcia et al., 2010 and Swarat et al., 2012 for example). This focus is also motivated by the assumption that personal interest tends to result in increased cognitive and affective processing (Ainley et al., 2002, Renninger & Su, 2012).

1.5 Content knowledge as demonstrated in different cognitive process levels

Bloom and colleagues (1956) provided a taxonomy of knowledge and cognition in which cognitive patterns are classified qualitatively into lower and higher order cognition. Lower order cognition encompasses knowledge, comprehension, and application, whereas analysis, synthesis, and evaluation characterize higher-order cognition (Barak & Dori, 2009). Other thinking skills such as problem-solving, decision-making, critical thinking, constructing arguments, creating research questions, and dealing with contradictions, also has been classified as a higher-order cognitive process (Zoller, 2000; Zohar & David, 2009). However, Anderson and colleagues (2001) suggested the necessity for improving the original version of Bloom's taxonomy to overcome the limitations of one-dimensional categorization and challenges of classifying cognitive levels associated with rigid hierarchical structure (Anderson et al., 2001; Krathwohl, 2002). The authors proposed a reform to define cognitive developments in a two-dimensional framework (i.e., including knowledge levels and cognitive process) and to refine the cognitive processes through verb forms (i.e. understand, explain, compare, create, etc.). Hence, Bloom's revised taxonomy has been used worldwide in science curriculum research (e.g., Lee, Kim & Yoon, 2015; Owens, Sadler, Barlow & Smith Walters, 2017).

Given that my study intends to analyze the relationships between levels of content knowledge cognition, Bloom's revised taxonomy may be the most appropriate framework (see **Table 1**). I will employ Bloom's revised taxonomy as a tool to analyze student cognition regarding their content knowledge. The levels of cognitive processes are classified into Remember, Understand, and Apply levels which are commonly considered lower-order thinking skills, while others categorized into the levels of Analyze, Evaluate, and Create are the higher-order thinking skills.

Table 1. *Levels of cognitive process in science learning (adapted from Krathwohl, 2002)*

Level of cognitive process	**Description**	**Example of content knowledge**
Creating	**Higher-Order Thinking**	Propose an experimental plan for testing the respiration of plant cells. Develop a hypothesis for testing ATP production in plant cells.
Evaluating		Compare amount of ATP produce in active and inactive cells. Interpret the collected data to support the hypothesis about ATP production.
Analyzing		Differentiate between aerobic and anaerobic respiration Compare and contrast between respiration process between plant and animal cells.
Applying	**Lower-Order Thinking**	Calculate the amount of ATP produce in muscle cell

Understanding		Explain the stages of glycolysis
Remembering		Name the enzyme involved and location of cellular respiration

1.6 Statement of problem

SSI-based curricula appear to be a viable means for promoting students' development of science literacy, providing relevance to scientific concepts in other contexts, and avenues for students to show their connection and making sense of science-related issues. However, the question remains how science content knowledge and SSI outcomes interact in a science course. Specifically, how do students use their scientific awareness to negotiate SSI in societal contexts and what is the relationship between content knowledge and students' reasoning competencies regarding socio-scientific issues? While some the studies has been carried out on the presumed relationship between understanding scientific knowledge behind the SSI and students' informal reasoning (e.g. Hogan, 2002; Levine & Barton, 2012; Lewis & Leach, 2006; Keselman et al., 2007; Sadler & Fowler, 2006; Venville & Dawson, 2010; Wu & Tsai, 2007), other studies have revealed that students' scientific understanding does not necessarily promote the quality of their reasoning about SSI (Zohar and Nemet, 2002; Sadler & Donnelly, 2006; Wu & Tsai, 2007). Because research has shown that the relation between content knowledge and students' reasoning is complex, we must better understand how students employ their understanding about science content to support their reasoning development. If the goal of science education is to prepare students to use their scientific knowledge in their everyday decision-making, an understanding of these issues needs to be a part of that goal.

In addition, several studies on SSI have argued that personal interest may motivate information processing and typically outweighs other affective considerations (e.g., caring for others and the environment) when individuals negotiate a resolution for SSI (Herman, 2015; Lehman & Crano, 2002). Further investigation is needed to explore how cognitive and affective factors, such as content knowledge and personal interest, affect students' thinking practices regarding SSI. In doing so, we will be better prepared to develop instruction that supports students with the development of higher-order thinking skills based on connecting science content knowledge and their personal interest. In fact, the relationship between content knowledge as demonstrated in different cognitive process levels and SSR has not been investigated rigorously (Romine et al., 2017). Therefore, in order to have deeper insight on this relationship with respect to science content and SSI outcomes, there is a need to investigate systematically the relationship between content knowledge and SSR in a series of scenarios throughout a science course.

1.7 Research questions

The following questions guide this research:

1. How do SSR sub-dimension competencies relate to one another? Do these relationships vary across scenario contexts?
2. How do SSR competencies, Content Knowledge, and Personal Interest vary across scenario contexts?
3. How do Content Knowledge and Personal Interest influence SSR competencies?

Research question 1: This question focuses on the SSR construct and explores the relatedness of SSR sub-dimensions within the SSR framework across multiple SSI scenarios. Specifically, the question will investigate the relatedness of SSR dimensions across three SSI scenarios. Since each dimension of the SSR framework has the potential to provide specific insight into students' ability to negotiate a unique SSI scenario, the investigation may illuminate the effect of SSI scenario contexts on specific SSR competencies regarding students' abilities to resolve multiple issues.

Research question 2: This question examines students' SSR competencies, Content Knowledge and Personal Interest across three SSI scenarios. Previous research suggests that the SSR patterns do likely not vary across scenarios contexts. However, the existing results are quite limited, investigating only two scenarios or small sample size (Romine et al., 2017; Sadler et al., 2011; Topcu et al., 2010). The goal of this question is therefore to explore how students demonstrate their SSR competencies along with Content Knowledge, and Personal Interest by conducting a study in large class sample size with three SSI scenarios related to three different science topics.

Research question 3: This question aims to test the influence of content knowledge and personal interest on students' SSR in order to identify a good fitting model. By determining the best fitting model, the aim would be to better understand the association between the factors and to investigate the extent to which the students' SSR varies from different SSI scenarios. For content knowledge, this question concentrates on the potential relationship between two levels of content knowledge as demonstrated in different cognitive processes (e.g., lower order thinking and higher order thinking). The content knowledge tests will be itemized for the two levels based on Bloom's revised taxonomy. This is necessary to see to what extent students' knowledge level obtained in science units can serve as a contributor for their SSR competencies.

It could be hypothesized that individuals with higher orders of thinking related to the content knowledge that underlies an SSI scenario would be more likely to develop SSR competencies than their peers who possessed lower orders of thinking related to content knowledge. Since the relationship between content knowledge and reasoning is complex, this is one of many possible associations I would like to address this by assessing the relationship between content knowledge as demonstrated in different cognitive process levels and SSR competencies. In addition, some studies suggest that a personal interest in the SSI scenarios may impact students' engagement in motivated reasoning (Ditto, Pizarro & Tannenbaum, 2009; Sadler & Zeidler, 2004; Ottander & Ekborg, 2012; Pintrich, Marx & Boyle, 1993). Nielsen (2012) also suggests that "socio-scientific decisions are not simply inferred from a range of factual premises; they will always reflect the ideological and personal principles to which the deciding party adheres" (p. 429). Taken together, not only the students' content knowledge but also the affecting aspects of their attitudes towards SSI should be taken into account. In addressing this question, I will analyze the presumed positive association between how much a personal interest in the SSI topic is connected to the quality of their reasoning. Structural equation modeling (SEM) techniques will be used to test the components of the interaction between SSR and other factors in SSI contexts and to identify a good fitting model based on the data. Determining whether SSR is influenced by other components in SSI context can lend support for more complex models with other variables in later research and lay the groundwork for additional empirical inquiry as to whether SSR can be improved in science classroom.

The research questions are visually displayed in the following model (**Figure 1**).

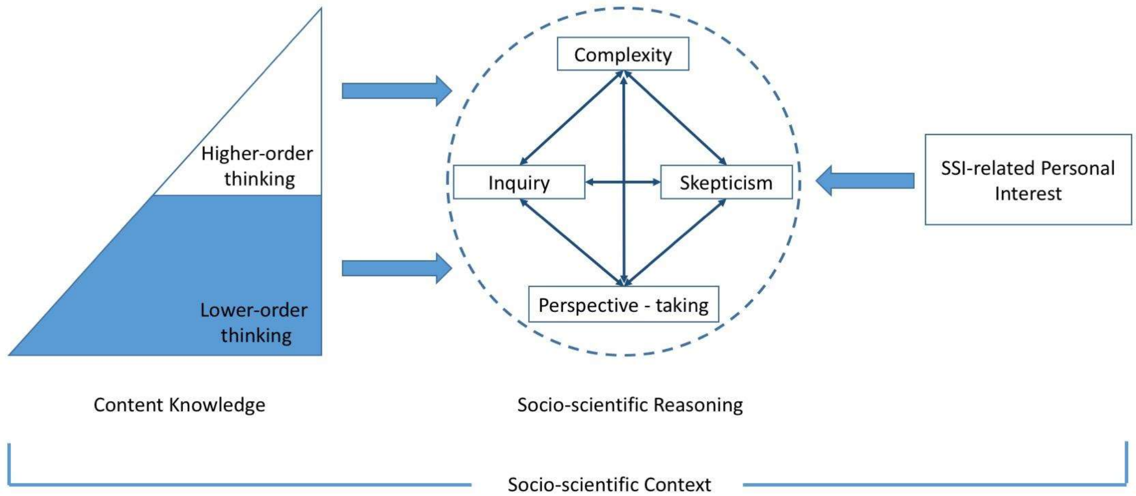


***Figure 1**. Model of the conceptual underpinnings of the study*

1.8 Significance of study

There have been no rigorous studies performed to determine relationships between SSR competencies and content knowledge related to SSI as demonstrated in different cognitive process levels. This is the first study that investigates different levels of content knowledge and personal interest as predictors of SSR, including examining the fitting models across three different SSI scenarios (i.e., Global Warming, GMOs, Vaccinations), which also adds to the novelty of existing empirical studies. Understanding the relationship between SSR competencies and the scores on the science content knowledge is important to science education curriculum makers, faculty, and students. Curriculum makers, as well as faculty, can adjust the curriculum based on knowledge of the correlation of SSR competencies to the assessment. If high level understanding of science content knowledge is found to be an important factor in developing SSR competencies, the faculty may find data from this study beneficial and begin to explore instructional strategies for teaching higher-order thinking skills related to science concepts throughout the curriculum. In addition, the correlation between the students' SSR competencies and content knowledge will also inform assessment design. Effective assessments can then be designed to reveal students' SSR competencies and have the potential to provide critical feedback to instructors and curriculum developers.

The information resulting from these questions should allow educators to become more knowledgeable about the effect of SSI-focused curriculum in their classroom setting on students' learning outcomes and how these effects would potentially address scientific literacy. This literature has the potential to highlight areas where instruction can better support the development of students' SSR competencies and address the degree to which content knowledge provided during instruction contributes to the development of students' higher-order thinking abilities. Additionally, the analysis of the relationship between content knowledge and SSR competencies will portray the depth of the interaction between Vision I and Vision II (Roberts, 2007) of science literacy (that is attempting to promote both retention and transfer in other contexts. Results will provide faculty with recommendations about how to develop meaningful SSI scenarios to support SSR development and how to integrate SSI into a science course with diverse topics. In addition, the SSR conceptual framework employed and scrutinized in this study will be helpful for science education researchers who want to explore the students' thinking practices regarding controversial contemporary issues. Finally, from this study, we explore and potentially learn from the implementation of a series of SSI scenarios utilized in teaching biology for non-majors students in a large class format.

CHAPTER 2 - LITERATURE REVIEW

The questions addressed in this research are whether there are relationships between SSR and factors within SSI context, including content knowledge and personal interest. In order to contextualize this research, the literature review will examine, in brief, three critical areas: a review of research related to SSR, personal interest, and relationship between SSR-like variables and content knowledge. To better understand the interplay between SSR and content knowledge in science learning, the revised Bloom's taxonomy (Anderson et al., 2001) and the SSR conceptual framework (Sadler et al., 2007) was used.

2.1 A Review about Socio-Scientific Reasoning

Nature of the SSR construct:

Science educators have suggested that SSI-based education has potential benefits for future citizens as promoting interactions with social issues, deepening sophisticated ideas about nature of science, making informed decisions on complex issues, and raising ethical awareness (Kolstø, 2001; Sadler, 2011; Zeidler & Sadler, 2008). Through the connecting of relevant SSI to science learning, students are expected to exercise their science understandings and practices to negotiate and resolve SSI. However, the assessment tools to better understand the ways in which students practice reasoning in context of SSI are not well-supported by evidence (Orpwood, 2007). Sadler et al. (2007) developed an SSR framework as a first effort to address the theoretical and practical gaps in the assessment of SSI-related outcomes. The researchers conceptualized the perception and practices about nature of SSI as "socio-scientific reasoning" (SSR) and defined it as "*a theoretical construct which subsumes aspects of practice associated with the negotiation of SSI and addresses the citizenship goal*" (p. 374). They hypothesized that as students have opportunities to experience with relevant SSI contexts, they are able to develop a more sophisticated reasoning and holistic understanding of the SSI. In the first attempt, SSR was employed as a tool to evaluate how students resolve an SSI after engaging in a simulated learning environment that addressed a complex environmental issue (Sadler et al., 2007).

The SSR was initially developed as an educational tool for both teachers and researchers to evaluate student thinking practices as they work to resolve complex SSI (Sadler et al., 2007). In that construct, SSR consists of four cognitive dimensions that are representative of informal reasoning to negotiate and resolve SSI, including (i) Complexity: recognizing the complexity of SSI; (ii) Perspective-taking: examining issues from multiple perspectives; (iii) Inquiry: appreciating the inquiry; and (iv) Skepticism: reviewing possibly biased information with skepticism.

Complexity: Most SSI are not "conducive to being decomposed and handled one dimension at a time but rather must be considered in all of their systemic *complexity*" (Hogan 2002, p. 364). Solutions for them are usually given as a range of possibilities, rather than as a single decision. "Complexity" is associated with the inherent multifaceted nature of SSI (Zeidler & Sadler, 2011). Since SSI is accessible to many possible solutions based on both social and scientific perspectives, people often confront with many disciplines and core beliefs, and gain experiences negotiating their inherent complexities (Zeidler, 2014). Thus, it was emphasized that individuals should recognize the complexity dimension in their reasoning (Hogan, 2002; Pedretti, 1999; Kinslow et al., 2019, Owens et al., 2019a; Sadler et al., 2007).

Perspective-taking: The complex structure of SSI involves morals, beliefs, ethics, values, multiplicity of views, and tension among different stakeholders (Goodnight 2005, Stewart, 2009, Karahan & Roehrig, 2017). "Perspectives" as a component of SSR relates to the negotiation and resolution of conflicts from different perspectives (Zeidler & Sadler, 2011, Newton & Zeidler, 2020). The authors emphasized that SSI includes dilemmas in which conflicting and/or biased information, views and values compete. In general, people experience different interests, ideas, priorities, and prejudices while reaching a consensus opinion (Sadler et al., 2007). Students with different stances should address the issue differently and protect their own arguments. Students who are able to explore SSI from multiple perspectives can provide more sophisticated reasoning on SSI and move toward more informed decisions as compared to the students who just hold single perspective in the negotiation and resolution of SSI (Sadler & Zeidler, 2005b; Zohar & Nemet, 2002, Kahn & Zeidler, 2016). In the original version of SSR, the perspectives dimension measured the degree to which students took "multiple perspectives" to explain their own positions (Sadler et al., 2007). Sadler and colleagues (2007) suggested that refined SSR around the perspective-taking dimension is necessary not only for assessing individual's competency to take other stakeholders' points of view into account, but also challenging one's own perspective in real-life contexts.

Inquiry: Inquiry practices are essential for supporting students to make the informed decisions required of modern society (Bingle & Gaskell, 1994; Yang & Anderson, 2003; Hofstein & Lunetta, 2004). The limitations of scientific research, even conflicting data, force students to consider the need for seeking additional information. "Inquiry" dimension of the SSR construct was conceptualized based on the uncertainty of SSI or data available (Sadler et al., 2007). The researchers defined that SSI are controversial, ill-structured issues subject to further inquiry (Zeidler et al., 2005; Sadler et al., 2007). These issues lack of information, which is necessary to be explored through ongoing research, particularly scientific data are generally not adequate to provide simple answers to complex SSI. Therefore, careful negotiation and resolution of SSI needs appropriate inquiry to support evidence-based decisions. Students who value opportunities to conduct inquiry-based investigations may develop more complex thinking about resolutions of SSI by requiring additional evidence or checking the information resources to reach a convincing solution.

Skepticism: Skepticism often comes with inconsistent information or suspending judgment until sufficient information is available (Sadler et al., 2007; Kinslow, 2018; Kinslow et al., 2019). The information presented in SSI usually goes along with potentially conflicting and/or biased resource. Interpreting evidence, looking for bias and underlying ideologies and values, is necessary for a critical evaluation of evidence (Kolstø 2000; Zeidler et al., 2002). Since skepticism has not been taught explicitly in school, the measurement of this competency associated with SSI is difficult (Sadler et al., 2007; Sadler et al., 2011). Students rarely provide direct evidence of skepticism through open-ended surveys (i.e. short responses); however, they can include the evidence of skepticism within their writings (i.e. position papers or learning logs) (Kinslow et al., 2019).

In the following, research on the measurement of students' SSR will briefly be reviewed alongside challenges that this construct may encounter. Researchers have employed different approaches to collect data on students' SSR competencies. Interview approach was used in the first study of SSR because it was able to provide insights into the perspectives of students (Sadler et al., 2007). These interviews were transcribed and scored based on an emergent four-level ordinal scale rubric. Some studies focus on open-ended ways of asking questions that prompt further students' reasoning (Sadler et al., 2011; Cansiz, 2014; Kinslow et al., 2019). Although researchers employed open-ended surveys, they concerned that fixed questions may cause to a misrepresentation of student's opinion. To address these concerns, Sadler et al. (2011) developed an adaptive online survey that allow to direct students to relevant open-ended questions based on prior compulsory preferential answers. By using this technique, the researchers can identify the complexity of student's reasoning in negotiation of SSI. In addition, the platform of adaptive online survey becomes feasible for collecting data from large population (Sadler et al., 2011; Romine et al., 2017).

Since the initial SSR framework was developed, a range of attempts has been proposed to assess students' SSR competencies in various SSI contexts. Researchers used both interviews and open-ended questionnaires as qualitative tools for uncovering themes and trends in students' SSR (Sadler et al., 2007; Topcu et al., 2010). Cansiz (2014) also used both surveys and interviews to explore SSR improvements of preservice teachers participating in a semester-long SSI-focused course. Much of her findings echo the report of Sadler et al. (2007). For instance, the preservice teachers also gained SSR competencies after exploring the proposal to build a nuclear power plant as a particular example of SSI throughout the course. Recently, high school students who engaged in an SSI field-based environmental education intervention showed that they gained SSR in Skepticism, Perspective-taking, and Inquiry competencies (Kinslow et al., 2019). Furthermore, students retained and even demonstrated slightly greater improvement of the Complexity competency six months later. The results from these studies indicate that open-ended questionnaires and interview can provide much information and insights about students' reasoning. In order to assess learners' SSR through these qualitative data, many scoring rubrics have been developed and employed. The use such rubrics has been demonstrated as a reliable strategy for performance assessment (Jonsson and Svingby, 2007). The original rubric focused on analyzing data obtained through interview data (Sadler et al., 2007). In the follow-up study, researchers revised the scoring rubrics by re-conceptualized the quality of the elements in each dimension, particularly in perspective dimension (Sadler et al., 2011). In order to measure deeper students' reasoning, Cansiz (2014) developed two separate rubrics, one for breath and one for depth. However, the original rubric has still been fine-tuned for improving the conceptual framework (Kinslow et al., 2019). Recently, researchers sought to expand and elaborate the dimensions of SSR construct and its assessment tools (Kinslow, 2018, doctoral dissertation). Owens and colleagues (2019a) have developed a five- point scale rubric (i.e. 0 - 4 points) based on the previous three-point scale rubric. Although these qualitative measurements have yielded valuable insights into student reasoning, there are significant limits in scaling to large populations. To overcome this issue, Romine and colleagues (2017) designed an instrument, named the Quantitative Assessment of SSR (QuASSR), which measures students' SSR within a larger sample. The QuASSR was tested and validated in a pilot study with college students through a one-week SSI intervention focusing on hydraulic fracturing ("called fracking") (Romine et al., 2017).

Important considerations

While evidence may support the increase of students' SSR competencies, many considerations should be addressed due to a complex array of factors related SSI context.

- **Scenarios**

One major issue in assessment of students' SSR that has dominated the field recently concerns the kinds of scenario contexts. In general, SSR instruments consisted of a narrative case which provides a storyboard of SSI to the students. This leads to questions important questions: What should the structure and the context of scenarios be? Do alternative scenarios trigger students' responses in different ways? While existing studies indicate that patterns of SSR competencies appear consistent across different contexts, the findings are fairly limited with very few scenarios introduced in each study (Sadler et al., 2007; Sadler et al., 2011; Romine et al., 2017). Sadler and colleagues (2007) found in their first report on SSR that students typically gained their SSR competencies better in response to the "*near-transfer context*" than the "*distant-transfer context*" (p.387). Cian (2020a) recently observed that high school students developed their SSR competencies differently depending on the SSI topics. Particularly, students gained more insights of Perspective-taking dimension in the environmental topic, while in the genetics scenario they tended to show their skepticism (Cian, 2020a).

- **Durations**

Interestingly, SSR competencies can change over time. However, the development can be varied depending on the duration of interventions. There was no significant change in SSR as a result of the short-duration SSI-based intervention. Sadler and colleagues' (2011) research included, for example, an SSR pre-/posttest examination in conjunction with a three-week SSI unit. The researchers have attempted to explore ways in which students' SSR can change through a variety of classroom implementations. No statistically significant differences found, however, between pre- and posttest can be reasonably attributed to the short-term intervention (Sadler et al., 2011). These findings are similar to those of developing higher-order thinking skills, which involve intensive and sustained interventions. Dori and colleagues (2003), for instance, designed complex case studies in biotechnology to support the development of high school students' higher order thinking skills over an academic year. Similarly, preservice teacher engaged a semester-long SSI-based intervention that explicitly focused on the interactions between science, technology, and society, showed some degrees of SSR improvement (Cansiz, 2014).

- **Teaching and learning context**

Previous research has presented little evidence of the development of students' SSR in conjunction with teaching and learning contexts (Sadler et al., 2007; 2011; Karahan & Roehrig 2017; Romine, et al., 2017). Recent findings support the idea that students' SSR competencies can be improved through meaningful experiences in a local SSI (Kinslow et al., 2019). These findings align with the situated learning theory (Brown et al. 1989; Sadler, 2009), which suggests that knowledge is constitutionally connected to the specific context in which it is learned. This perspective emphasizes the contextualization of teaching and learning in authentic environments. Clarification of SSI instructional context is therefore necessary to promote SSR development while students engage in various learning experiences.

Correlations among dimensions

Drawing on four specific practices related to SSI negotiation and resolution, Sadler et al. (2007) conceptualized SSR construct as four interrelated dimensions. In the original SSR study, complexity and inquiry associations were found relatively strong while others were weak (Sadler et al., 2007). However, in a follow-up study, no evidence of relationships among three aspects: complexity, inquiry, and perspective-taking were found (Sadler et al., 2011). Researchers suggested evidence of relationships among the three aspects were identified but it was not clear.

Table 2. *Empirical studies on SSR construct*

Author(s)	**Student Levels**	**Intervention duration**	**Assessment**	**Findings**
Sadler, Klosterman, & Topcu (2011)	High school	**3 weeks**	Adaptive, online open-ended survey with SSR rubric	There was no statistically significant variation in pre-and post-test of the intervention
Cansiz, N. (2014)	College	**10-15 weeks**	Interview protocol with SSR rubrics	Preservice teachers participated in a course that emphasized on the links between science, technology, and society, and showed the development of their SSR competencies.
Romine, Sadler & Kinslow (2016)	College	**1 week**	Online multiple-choice survey (QuASSR)	There is also some variability between two scenarios.
Kinslow, Sadler &	High school	**6 weeks**	Online open-ended survey	SSR and environmental literacy skills develop through an SSI field-based

Nguyen, (2018)			(QuASSR-oe, student learning logs, and summative position paper with SSR rubric	environmental education program. Students quantitatively demonstrated a substantial improvement in the SSR competencies associated with Complexity, Perspective-taking, and Inquiry.
Cian (2020a, b)	High school	**N/A**	Online multiple-choice survey (QuASSR)	Students demonstrated their SSR competencies differently depending on the SSI topics. Their knowledge, values, and experiences were also associated with their SSR.

Several other groups have attempted to account other components of the SSR construct in various ways (e.g., Simonneaux and Simonneaux, 2009; Eggert and Bogeholz, 2010; Morin et al., 2014). Simonneaux and Simeonneaux (2009), for example, extended the SSR framework by introducing two components: risk / uncertainty identifying and decision-making on culture and ethical values. Morin and colleagues (2013, 2014), by adding considerations and emphasizing on sustainability, have further developed their SSR model. Eggert and Bogeholz (2010) promoted the idea of “socio-scientific decision-making" included to the SSR construct. Recently, Karahan & Roehrig (2017) have proposed three more aspects for the SSR theoretical construct, including (1) recognition of social domains influencing the SSI, (2) utilizing cost and benefit analysis for evaluation of claims, and (3) insight into SSI context. However, these expansions seem likely related to content knowledge and skills as working in SSI context rather than conceptualizing and reasoning. It remains unconvincing to me if these expansions eventually improve SSR as a construct useful for evaluating and supporting the thinking of students in the sense of SSI interventions.. For this reason, I have argued to define the SSR construct regarding four cognitive practices which are fundamental elements of the negotiation and resolution of SSI. I consistently view these four practices as constitutive components in advancing SSR. While I appreciate the attempts of numerous groups working in science education to advance research in SSR, I decide to use the original four-dimensional SSR framework, including Complexity, Perspective-taking, Inquiry, and Skepticism (Sadler et al., 2007). Thus, this decision naturally drives to questions about the relations of components within the construct and other variables which may be involved in learning contexts as students engage in SSI scenarios.

Summary

Generally, SSR is described as "*means of understanding student practices relative to the invariant features of SSI*" (Sadler et al., 2011, p.46). The SSR conceptual construct was designed with four different dimensions (i.e. Complexity, Perspective-taking, Inquiry, and Skepticism) to capture the reasoning practices in which people can be expected to engage in SSI contexts. With this view, SSR represents as a conceptual framework, strengthening its persuasive aspect and putting forth an explanation that justifies the learner's reasoning. The interview protocol employed for initial study offered quality results, but the requirements to transcribe and interpret interviews would possibly preclude its use in large-scale projects. In contrast, the adaptive surveys such as QuASSR was demonstrated as a reliable and valid research instrument for exploring student reasoning. The literature has proposed that SSR improvement may involve longer developmental periods and relate to other factors in SSI context. However, no study systematically collects data on the student's interest or their motivation to engage in SSI learning activities. In order to advance SSR as a useful framework for research in science education, evaluation of its aspects would need to be improved.

2.2. Personal Interest in Science Learning

Nature of interest

In the field of science education, interest has seen as a central concept for learning and teaching (Krapp & Prenzel, 2011). Indeed, interest is an affective construct which alludes to the liking and pleasure of being engaged in tasks as well as the wish to acquire information (Hidi & Renninger, 2006). Studies of interest in the education field has classified interest with two meanings: the psychological status of an individual engaging with specific contents and the cognitive and affective motivational tendency to reconnect with that content over a period (Renninger & Hidi, 2016). Although there are many ways to define interest, it is usually recognized with five characteristics: content or object specific, related to environment and sustained through interaction, involved in both affective (good feelings) and cognitive aspects (want to learn), not be aware during engagement, and related to physiological or neurological basis (Renninger & Hidi, 2011). Interest may be either situational or individual (Hidi & Renninger, 2006; Krapp & Prenzel, 2011). The first applies to a temporary psychological state and emotional response triggered by external factors; the second refers to a relatively long-lasting re-engagement propensity. Hidi and Renniger (2006) proposed that interest growth takes place across four stages: triggering situational interest, retaining situational interest, forming individual interest, and well-established individual interest. In that model, situational interest could develop into and occur simultaneously with individual interest (Renninger & Su, 2012).

Relationship between interest and cognitive process

Educators and researchers appreciate interest as a critical indicator of learning when they have found that interest can influence on students' academic success and it can be retained over time (Arnone, Small, Chauncey & McKenna, 2011; Krapp, 2002; Linnenbrink-Garcia, Patall & Messersmith, 2013; Renninger & Hidi, 2016). The sense of interest includes positive feelings (affect), concentration and propensity towards action (motivation), and knowledge quest (cognition). Many studies have suggested that positive impact of interest toward science is fundamental to students' persistence and success in science learning (Schiefele, Krapp & Winteler, 1992; Singh, Granville & Dika, 2002, Potvin & Hasni, 2014). The majority of existing educational studies on interest have examined both its short-term and long-term effects on learning and have showed that it has been associated with deeper processing of information (Schiefele 1991, 1999; Ainley, et al., 2002; Wigfield & Cambria, 2010), focusing attention (McDaniel et al., 2000), and reading strategies (Ainley et al. 2002, Schroeder, 2013). Research on the development of interest suggests that interest can be a powerful predictor of career choices (Harackiewicz et al., 2002). Some studies indicated that young students come into school with their curiosity in science, and their interest diminished as a result of the way science is taught (e.g., Trumper, 2006; Barmby, Kind, & Jones, 2008). Krapp and Prenzel (2011) also found that many associations between interest and academic achievement are not always significant. The authors noted that "students with a high cognitive potential for science do not pursue careers as scientists or engineers because they lost their interest during school" (p. 42). Elucidating the reciprocal relationship between interest and cognition as students engage in science lessons, therefore, appears to be a need to develop curricula as well as design the necessary teaching strategies.

While much is known about the roles of interest in learning, little is known about relationship between cognitive process and personal interest. In early studies, researchers found that students who displayed a higher understanding of prior knowledge would be more interested in the subject (Alexander et al. 1996; Tobias 1994). However, Kintch (1980) proposed that the association between interests and previous knowledge was curvilinear in nature, since stages of strong interest were followed by stages of little interest among students who had previous knowledge. Yarlas and Gelman (1998) also found curvilinear relationships between the influence of novelty and text form on interest. The researchers suggested that passages in college classes that induced higher amounts of perceived learning can increase students' interest, and passages that provided lower amounts of new information can significantly reduce students' interest. Many later studies confirmed that meaningful activities in classroom can support personal interest develop (Swarate et al, 2012; Taskinen, Schutte & Prenzel, 2013; Tomas et al., 2011; Renninger & Bachrach, 2015). Recently, Rotgans & Schmidt (2018) suggested that "interest is an affective-by-product of content knowledge" (p.352). The result showed that the growth of interest in particular area of learning can be seen as a result of awareness development. However, Brandmo and Bråten (2018) argued that student's interest in learning of SSI topics might mediate the effects of epistemic beliefs on science knowledge. Although the study could not answer the cause-effect, its results indicated that epistemic beliefs may both positively and negatively influence on content knowledge mediated by topic interests. Because content knowledge plays a central role in cognitive process (Barsalou et al., 2003), this substantial work leaves a significant gap in our understanding of relationship between personal interest and cognitive process regarding scientific content knowledge when individuals negotiate a resolution for SSI. Table 3 summarizes the research methods and results of the most recent empirical studies on personal interest and content knowledge.

Table 3*. Empirical studies on personal interest and content knowledge*

Author(s)	**Student Level**	**Methods**	**Key Findings**
Brandmo & Bråten (2018)	High school	Quantitative method (SEM)	Personal interest mediated the effects of epistemic belief on science knowledge in two SSI topics (i.e., climate change and nuclear power).
Rotgans & Schmidt (2018)	Elementary & Middle school	Quantitative method (SEM)	Personal interest does not directly influence subsequent content knowledge and its effect is mediated by situational interest.
Rotgans & Schmidt (2017)	Elementary & Middle school	Quantitative method (Cross-lagged panel analysis, quasi-experimental studies)	Knowledge determines interest rather than the other ways. The findings support the effective-by-product hypothesis of interest, which suggests that interest is an affective by-product of knowledge.
Taskinen, Schütte & Prenzel (2013)	Ninth grade	Quantitative method (PISA analysis; SEM)	Students became more interested in science when their science teachers emphasized more on real applications. School learning significantly influences the interest of students in science and indirectly affects subsequent motivation of students to study science.

Swarate, Ortony & Revelle (2012)	Sixth & Seventh	Mixed methods (survey and interview)	"Hands-on" activities and the possibilities to interact with the technologies strongly affect students' growing interest in science far beyond content subjects or specific learning goals.
Tomas, Ritchie & Tones (2011)	Ninth grade	Qualitative method (Case study)	Students' emotions during a unit that focused on energy controversy (coal seam gas) can impact on their engagement interest, motivation, and learning in science. The findings support that writing hybridized scientific narratives about SSI enhances students' interest in learning science.
Singh, Granville & Dika (2002).	Eighth	Quantitative method (Linear structural relations (LISREL) analysis)	Attitude toward science and motivation had indirect but significant effects on student's science learning.

Student's Personal Interest in SSI learning

SSI learning may occur either in classrooms or in everyday situations (Sadler, 2011). Engaging in SSI in varied learning environments may enhance student's interest of learning in school subjects (Lindahl et al., 2011, Ottander & Ekborg, 2012). According to a four-year study in Sweden, students at senior level showed their interest in working with SSI, particularly the interesting and relevant issues, and they believe that SSI can improve their learning in science (Lindahl et al., 2011). However, SSI may not so much increase students' interest in science in general, but some students say they can learn a lot while negotiating a dilemma (Ottander & Ekborg, 2012). Many SSI stem from dilemmas involving environmental problems and humanistic perspective. When students engage in SSI, they usually are encouraged to articulate an argument and rationale describing whether they would support. It seems that the students are more inspired by such a social relevance. In addition, some SSI often relate to contemporary innovation and inventions that could attract student attention (Ratcliffe and Grace 2003). Levison (2008) suggested that the controversial issues address in a classroom could be emerged from interests of students. The interest and engagement of students in a topic appears rational to strengthen their argument on the related issue. Students might model the roles of stakeholder interests within SSI contexts. The contextual engagement can facilitate students to explicit in discussions and then help them gain scientific content and epistemological understandings around the issue (Sadler & Dawson, 2012; Lederman, Antink, & Bartos, 2014; Brandmo & Bråten, 2018). However, how the students' interest in SSI can be developed and maintained through the SSI instruction has not been systematically examined.

Summary

Interest, one of the most important motivating factors, significantly affects student achievement and results in higher cognitive process (Ainley et al., 2002;

Hidi, 1990; Schiefele, 1999). While situational interest refers to a temporary psychological condition triggered by external factors, personal interest refers to a relatively permanent engagement. Many studies have shown the positive influence of interest on science learning in terms of increasing cognition (e.g., Renninger et al., 2014; Schiefele, 1999; Tobias, 1994). When students are interested in a subject, they tend to focus on the relevant content and are eventually more engaged in learning activities. Many studies have suggested that positive impact of interest toward science are fundamental to students' persistence and success in science learning (e.g., Singh, Granville, & Dika, 2002; Swarate et al., 2012; Taskinen et al., 2013; Tomas et al., 2011). While relationship between interest and previous knowledge was proposed to be curvilinear (Alexander et al., 1996, Kintsch, 1980), there is a significant gap in the literature around examining specifically how personal interest relates to SSR competencies as well as cognitive process as students engaged in SSI contexts. Therefore, a study is needed to identify and develop the relationships between motivated behavior and cognition and emotions during learning from SSI that can support students' development in science literacy.

2.3. Relationship between SSR-like variables and Content Knowledge

When students attempt to resolve SSI, they not only apply and integrate relevant learned concepts, but also practice informal reasoning, argument, and decision-making. In this session I focus on relationships between those SSR-like variables and content knowledge. **Table 4** summarizes empirical studies on relationship between SSR-like variables and content knowledge. Although the role of content knowledge is not explicit in most definition, it is assumed that students refer their content knowledge in their argumentation or decision-making process.

Table 4. *Empirical studies on relationship between SSR-like variables and content knowledge*

Author(s), Year	**Major Findings (in relation to Content Knowledge)**
Albe, 2008	Professional students in Tunisia appeared to ignore scientific evidence before the intervention. After the intervention, students tended to consider and use scientific evidence in their decisions associated socio-scientific issues.
Christenson, Rundgren, & Zeidler, 2014	Social science students in Sweden have offered more justifications than cohorts from science majors. Science students, however, provided more scientific evidence-based justifications.
Dawson & Venville, 2010	Australian high school students did not use data or evidence frequently in order to substantiate their arguments in informal reasoning about biotechnology issues. They also offered more intuitive and emotional informal reasoning than rational.
Keselman, Kaufman, Kramer, & Patel, 2007	Middle-school students improved critical reasoning by *strengthening their conceptual understanding* of HIV biology through 4-week intervention.
Klosterman & Sadler, 2010	Distal and proximity assessment showed students expressing more comprehensive and more informative understanding of SSI after the three-week Global Warming unit.
Levine & Barton, 2012	Middle-school students' scientific knowledge influenced their negotiation about socio-scientific issues, including recognizing the multi-dimensional nature of the problem and proposing complex solutions.
Lewis & Leach, 2006	Student's disciplinary knowledge largely determined her/his ability of discussing in SSI arising from biotechnology. Understanding science content knowledge was important in helping students identify and elaborate their point of view to resolve an argument.

Lindahl & Lundin, 2016	Students use their knowledge of scientific disciplines, either as a sole reasoning or combined with other types of knowledge, to support their reasoning in SSI regarding human sexuality.
Nielsen, 2012	Students (aged 16-19) in Denmark often called science content in their discussion about human gene therapy.
Sadler & Donnelly, 2006	Genetics content knowledge was not necessarily supporting the quality of argumentation. Students who scored high on genetic tests were not more likely to show better arguments than their low-scoring peers.
Sadler & Fowler, 2006	Science students demonstrated higher quality arguments than other groups. The quality of their arguments did not vary significantly between non-science and high school students.
Sadler & Zeidler, 2005a	Students with a more sophisticated understanding of genetics had less cases of reasoning flaws and were more likely than those with naiver genetic knowledge to use content knowledge in their reasoning.
Sadler, 2005	No non-science college students have spoken about evolution, but 53 percent of the biology students have taken evolutionary views as genetic engineering issues have been discussed.
Sadler, Romine, & Topçu, 2016	SSI-based teaching has been shown to promote the students' knowledge of molecular biology and genetics-related science principles in high schools.
Topcu, Sadler & Yilmaz-Tuzun, 2010	The quality of informal reasoning among different SSI scenarios was very consistent.
Venville & Dawson, 2010	High school students in argumentation groups significantly improved the quality of their arguments and their genetic understanding.
Wu & Tsai, 2007	Taiwanese high school students prefer to use scientific or technology-oriented arguments to help their informal reasoning and decision-making on controversial topics.

Wu, 2013	College students, showing their expanded and structured scientific knowledge, offered likely multiple perspectives and achieved a higher quality of informal reasoning on SSI concerning genetically engineered foods.
Zohar & Nemet, 2002	Students participating in dilemma discussion scored significantly higher than other groups and they showed their improved argument quality.

Many studies in science education presupposes that the content knowledge of a person contributes significantly to his or her reasoning as a scientific controversy is addressed (Yang & Anderson, 2003). Most of the articles described that content knowledge plays an important role to support student's informal reasoning (e.g, Hogan, 2002; Rose & Barton, 2012; Lewis & Leach, 2006; Keselmanm et al., 2007; Sadler & Fowler, 2006). As working with eight-grade students, Hogan (2002) reported that students with deeper understanding of ecological knowledge demonstrated high-quality argumentation and informal reasoning regarding environmental problems. Similarly, Sadler & Fowler (2006) found that students in science disciplines offered higher quality argumentation than the other cohorts, and no substantial difference in their argumentation quality was shown by non-science majors and high school students. They argued that the quality of well-organized knowledge supports students' content knowledge understanding for the performance of higher-level socio-scientific arguments. The other study also reports a similar idea regarding students' lack of understanding of basic scientific concepts (e.g., genes and proteins) hindering their ability to reason (Duncan & Reiser, 2007).

However, a few studies also revealed that the science background of students does not necessarily promote the quality of their reasoning about SSI (Zohar and Nemet, 2002; Sadler & Donnelly, 2006; Wu & Tsai, 2007). Since argumentation has considered as an effective means of accessing a student's informal reasoning (Kuhn, 1991; Shaw, 1996; Zohar & Nemet, 2002; Sadler, 2004), many studies in science education investigate the quality of student's arguments through SSI. In a study of argumentation patterns associated with controversial issues, Zohar and Nemet (2002) noted that argumentation skills do not necessarily change with better conceptual understanding. The authors found that content knowledge did not play a major role in students' argument quality. Students who achieved well on genetic tests, for instance, were not more likely to provide high-quality arguments than low-scoring peers. Sadler and Donnelly (2006) proposed a "*Threshold Model of Content Knowledge Transfer"* (p.4), which hypothesizes that the quality of argument is associated with the level of content knowledge, but the relationship is not linear. Similarly, Wu and Tsai (2007) found that the students, who had already learned about the basic knowledge about nuclear power, appeared relatively less "science-oriented or technology-oriented" in their argumentation and did not seem to have adequate skills to connect what they had learned in the science classroom with the SSI they encountered. This result can be interpreted that students could understand the content knowledge but either they do not know how to transfer into their claims, or they prefer social perspectives. In both scenarios, science educators suggested that teachers should pay greater attention to students' ability to use their acquired scientific knowledge to resolve real-world problems (Sadler & Donnelly, 2006; Wu & Tsai, 2007).

In order to explore the structure of knowledge, Wu (2013) used multidimensional analyses for a study with high-school students in Taiwan. The study found that students with more advanced and structured knowledge systems relied more on multiple perspectives as controversies were introduced and negotiated. They also tended to achieve a higher level of informal reasoning. Although the quantity of knowledge structures of students is the only relevant indicator for their rebuttal construction, the results show that well-organized knowledge structures of students can help to transfer the content knowledge into their informal SSI reasoning (Wu, 2013). The study also found that students' knowledge gained in science classroom may serve as reference resources for their informal reasoning on SSI. In other words, understanding of relevant concepts to a controversial issue is necessary for high-quality argumentation. However, it is still difficult to conclude that this relationship is certainly cause-effect.

Many studies show students rarely refer science content knowledge in their reasoning while engaging in SSI (Dawson & Venville, 2009; Karahan & Roehrig, 2016; Morin et al., 2014; Sadler & Donnelly, 2006; Yang & Anderson, 2010).

They tend to rely more heavily ethical, feelings, societal, or economic factor rather than on scientific information. Clearly, reasoning in science requires content knowledge in the SSI interventions. However, answering how we know and why we know is also dependent on knowledge of the standard procedures used by science and the epistemic constructs and criteria that guide practice (Osborne, 2013). Research indicates that a complex interplay of factors (e.g., cognitive, effective, contextual) influence students' ability to reason scientifically (e.g., Zeidler, Sadler, Simmons & Howes, 2005; Zeidler, Herman, Ruzek, Linder, & Lin, 2013).

Content knowledge, while important, is not the sole factor of successful reasoning. In fact, many studies show that people usually connect their arguments with humanistic perspective and human values while negotiating SSI (Grace & Ratcliffe, 2002; Sadler and Donnelly, 2006). For instance, Sadler and Donnelly (2006) showed that students tend to apply very little science knowledge learned in science class when they negotiate with controversial issues related to genetics. Students' reasoning on SSI appeared to be not only affected by their conceptual understanding but also their divergent views about the problem presented. Lindahl & Lundin (2016) conducted a qualitative analysis to detect how high school students use scientific information to explain their reasoning on the topic of human sexuality in a science study course. In their discussions on the SSI, students were found to make use of science content knowledge with or without other sources of knowledge or personal experiences. In particular, students seemed to trust and use expert knowledge to reinforce their position. Although students referred to expert knowledge, they also showed an awareness of the limitations associated with human actions. This result is in coherence with previous studies on various SSI that reported that students need rather than only scientific knowledge to support their reasoning, particularly in complex dilemmas. In addition, student's disciplinary knowledge is largely represented in the discourse of student when he or she makes an argument (Christenson, et al., 2014; Lewis & Leach, 2006; Nielsen, 2012; Yang & Anderson, 2010). For example, Nielsen (2012) found that science content knowledge about genetics was represented through three ways in student's discussion: "explicit expressions of science content"; "assertive expressions of science content"; and "expressions with implicit science content". Nielsen asserted "science content played a strong role in responses to previous lines of arguing by introducing, or directly framing, an issue as well as providing argumentative support for a specific position toward that (framed) issue" (p.447). This finding elaborates on previous observation (Lewis & Leach, 2006) on the same SSI arising from the use of gene technology.

Although there has been a significant growth in publications on relationship between content knowledge and reasoning in the last 20 years, there are few quantitative studies, mainly qualitative methods were used (e.g., Bell & Lederman, 2003; Hogan, 2002; Sadler, 2005; Sadler & Zeidler, 2004, 2005a,b; Yang, 2004;

Yang & Anderson, 2003). Science education scholars have suggested some quantitative indicators to reflect the informal reasoning of learners, such as analyzing number of "arguments", "counter-arguments", "warrants", "claims", "qualifiers" appeared in students' discourse (e.g., Schwarz, Neuman, Gil, & Ilya, 2003; Sadler & Donnelly, 2006; Venville & Dawson, 2010). The use of such quantitative measures can provide researchers with insights into the relationship between reasoning and awareness of scientific content. Recently, researchers have attempted to propose several frameworks integrating the qualitative aspects and quantitative for measure relationship between students' informal reasoning with other factors in SSI context (Wu & Tsai, 2007; Romine et al., 2017, Kinslow, 2018, Owens et al., 2019a).

Summary

Content knowledge is often seen as the core component of scientific literacy (e.g., Hurd 1998, Ryder 2001). From the present point of view of science literacy, scientific knowledge and the use of such knowledge are required to understand real-life issues (Roberts, 2007). In order to assess, however, how students cope with science-related problems in their lives, an examination of content knowledge must be combined with the students' reasoning abilities to make informed decisions. The ability to make informed decisions on scientific and societal problems is proposed as an essential component of scientific literacy.

Thus, it is important to elaborate both the content of learning (the what) and the process of reasoning (the how) about the issues that knowledge used. Although there have been many studies on relationship between content knowledge and SSR-like variables, there are very few quantitative studies.

Overall Summary

Researchers have suggested that content knowledge can impact the development of informal reasoning and higher-order thinking skills (Zohar & Nemet, 2002; Sadler & Zeidler, 2005a). Sadler et al. (2007) suggested a conceptual framework for the investigation of the SSR while students engage in SSI learning. The framework contains four dimensions of informal reasoning regarding SSI, including *Complexity, Inquiry, Perspective-taking, and Skepticism*. This framework provides an approach for exploring the students' thinking practices on SSI and their relationships with other cognition processes. While the literature reveals no consensus definition of reasoning, there are some similarities found in SSR-like variables regarding negotiation of complex issues. Informal reasoning is generally regarded as a construct to capture the cognitive and affective processes that contribute to the resolution of SSI. Argumentation has been regarded as an effective means of accessing a student's informal reasoning or closely associated with higher-order thinking. As extensively discussed above, the studies in this field show that there a variety of relationships between SSR-like variables with content knowledge. Some studies suggest that content knowledge can help promote SSR-like variables. There are numerous factors in SSI learning context may affect students’ cognition. Although the empirical research provided in the literature contribute to clarify of how content knowledge and reasoning interact in certain contexts, they do not fully account for the change of student's reasoning construct through the course. Thus, an empirical study to explore the relationship between content knowledge and scientific reasoning is needed. In addition, personal interest in SSI is one intuitive appeal that may promote students’ learning and develop higher-order cognition. Many of the studies of interest in science learning showed that personal interest can be a predictor of learning. However, relationship between personal interest and SSR or SSR-like variables has not been investigated.

CHAPTER 3 – THE RESEARCH PROCESS

3.1 Introduction

The review of literature has shown that SSI-based teaching can offer an efficient way to promote learning aligned with scientific literacy goals, especially promoting significant higher-order thinking for students (Sadler et al., 2011; Zeidler, 2014). There is, however, a significant gap in the research base examining students' higher order thinking development through scientific reasoning-driven curriculum. To assess student's higher-order thinking that focuses on such issues, we need more assessment tools that allow instructors to capture effectively students' thinking practices as well as enhance their reasoning development throughout the course. This study aimed to improve the field's understanding of SSR by investigating student's SSR in relation with other factors in SSI contexts. It is expected that practices and perceptions in an SSI-integrated course may influence on students' SSR. Understanding how students shift their reasoning and their views about the SSI is important because the extent to which a new scientific concept is learned and understood largely based on what students negotiate and how they appreciate doing for next steps. Furthermore, clarification of the relationships among SSR aspects and science content will aid researchers in understanding the gaps in their work as well as connections with current SSR construct.

3.2 Research Questions

The following research questions were developed in order to guide the study.

- *Research question 1:* How do SSR sub-dimension competencies relate to one another? Do these relationships vary across scenario contexts?
- *Research question 2:* How do SSR competencies, Content Knowledge, and Personal Interest vary across scenario contexts?
- *Research question 3:* How do Content Knowledge and Personal Interest influence on SSR competencies?

3.3 Hypotheses

There are three developed hypotheses with the research questions. These hypotheses are described in the following:

- H1: There are differences between SSR competencies performed across three SSI scenarios.
- H2: There are correlations between SSR sub-dimensions competencies performed across three SSI scenarios.

- H3: There are significant influences of content knowledge and personal interest on SSR competencies

3.4 Data collection

Population:

The target population for this study is non-major undergraduate students enrolled in a General Biology course at the University of Missouri-Columbia. This course is an introductory biology course for non-science majors. As described in the syllabus, this course emphasizes connections and applications of general ideas and fundamental concepts of living things to human society, science literacy, and critical thinking skills. It is a 3-credit lecture course and average 400 students per section per semester. The course does not require any prerequisite for enrollment. Students enter this class with various degrees of enthusiasm. Many of them have had poor experiences about science and generally think that they were not able to do science. Many others just want to satisfy their degree requirements. This class was designed as a flipped instruction, in which student are given readings and watching assigned videos or animations before coming to class. In the classroom, the instructor gives a 20-min lecture and focuses on active learning such as discussion, think-pair-share, quiz, and formative assessments. This course is selected because it has been designed for non-science students and addresses various controversies in biology. Another reason this course is selected is because of the instructor. The instructor of this class has showed interest in SSI and has implemented SSI-based instruction.

Sampling Procedures:

I administered all related assessments through the Canvas, an instructional platform used in the University of Missouri. Three units were investigated in this study, including (1) Metabolism, Global Climate Change, Genes, and their Use; (2) GMOs, Cancer, and Human Reproduction ; (3) The Immune System and Evolution. After students had attended the first-week lectures of each unit in classroom, the QuASSR and Personal Interest surveys were delivered through their Canvas account in the following week. In the last week of each unit, the Content Knowledge assessments were collected through their unit exams. Figure 5 summarizes the science units in the course and procedure involved in data collection of this study. In total there were 212 students who agreed to participate this study. Written permission to survey these students was attained from the University of Missouri IRB approval.

***Table 5**. Timeline of data collection events*

Week	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Unit	Biology is the Science of Life			Metabolism, Global Climate Change, Genes, and their Use			GMOs, Cancer, and Human Reproduction			Genetics, Stem cells, and Infectious Diseases			The Immune System and Evolution		
QuASSR & Personal Interest Survey					•			•						•	
Content Knowledge Assessment						•			•						•

Note: Black dots represent the time points of data collection

3.5 Research Design

The design of this study is informed by the literature that documents how content knowledge, and personal interest could influence student's reasoning (e.g., Zohar & Nemet, 2002; Zeidler, & Keefer, 2003; Sadler & Zeidler, 2005a; Hidi, & Renninger, 2006). Studies in this area supports a hypothesized connection between conceptual understanding and personal interest in science topics and reasoning (Krapp & Prenzel, 2011; Renninger, 2009, Brandmo & Bråten, 2018). Quantitative methodology will be chosen for this research because of two reasons: first, the intent of the study is to analyze the multiple correlations among the SSR construct and between SSR with other factors in SSI context; second, the target variables are clearly defined and represented under numerical data. Because the research questions are classified into relational types, correlation non-experimental research design as suggested by Edmonds and Kennedy (2016) is chosen. The aim of a correlation research design is to explore relationships between at least two variables by using correlation statistics (Borg & Gall, 2004; Edmonds & Kennedy, 2016). This design allows for studying of individual variables without control groups. While a proper experiment comprises (a) pre/post-test design, (b) a treatment group and control group and (c) random assignment of study participants, not all these are necessary for this non-experimental study. One of advantages of this design is that the researcher can employ the analysis of relationships among a large number of variables within a single study, which is considered a more practical approach to research in social and behavior research (Edmonds & Kennedy, 2016). Correlation statistic also allows for the analysis of how multiple independent variables, either single or in combination, might affect a dependent variable, and it provides rich insights concerning the degree of relationship between the variables being studied (Borg & Gall, 2004).

In order to address the research questions, this study will comprise multiple surveys and tests, including measures of SSR, content knowledge, and personal interest. Fink (2012) stated that a survey is a scientific method to collect information from individuals to understand their value and knowledge about particular programs or activities. The data acquired to determine individuals' thinking should be supported by a valid survey instrument.

In order to achieve the objectives of this study, repeated-measured ANOVA, correlation tests, and structural equation modeling (SEM) will be performed with *SPSS* 21.0 and *MPlus*. First, repeated ANOVA tests were employed to examine the effectiveness of SSI scenarios on the four dimensions of SSR, content knowledge, and personal interest. Second, a correlation matrix will be used to investigate the relationship between content knowledge, personal interest and SSR competencies. The correlation test also will be used to examine the relatedness between 4 dimensions of SSR construct. Finally, SEM will be performed to test the influence of content knowledge and personal interest on SSR in a proposed model.

The following paragraphs describe the data collection, instrumentation, and data analysis that will be used for the completion of this study.

3.6 Research Instruments

3.6.1 SSR Assessment:

According to the literature, researchers have used different methods to collect data about students' SSR competencies. An interview approach was used in the first study of SSR because it was able to provide insights into the perspectives of students (Sadler et al., 2007). However, this initial study did not explore the extent to which measurement that can be helpful to capture students' SSR change through the SSI-based instruction. Later, Sadler and colleagues (2011) developed an online survey to assess high school students' SSR change through implementation of 3- week global climate change unit in classroom. While the SSR assessment based on an interview requires many resources for conducting and analyzing, many researchers prefer the survey approach since it can offer a cost-effective way to include a large number of students and broad range of aspects of practices (e.g Eggert & Bogeholz, 2010; Sadler et al., 2011). Recently, Romine and colleagues (2016) developed a new quantitative instrument for measuring SSR. QuASSR with multiple choice questions overcome some of the limitations of previous surveys through adaptive testing that allows students to select the best reasons that support their previous response. QuASSR can help to explore a complex construct like SSR and provide quantitative theoretical insight into the construct.

The basic structures of the QuASSR are a brief overview of an SSI and a series of multiple-choice questions using a two-tiered, ordered multi-choice (OMC) sequence (Briggs, Alonzo, Schwab & Wilson, 2006; Romine et al., 2017). This assessment tool is designed for online and adaptive testing. I use software Qualtrics that enables adaptive testing procedures and provides large-scale evaluation. The first tier asks students to answer a yes / no question (e.g., Is the problem easy to resolve?). After student's response to the question of the first tier, a second-tier question is immediately navigated and asked to choose the best explanation for their previous reply. There are three answer options to second tier questions that reflect an ordinal scale based on reasoning patterns observed in our previous interview and open-ended SSR surveys (Sadler et al., 2007; Sadler et al., 2011). For each SSR scenario, a wide array of questions has been developed: Complexity - two questions, Perspective-taking - two questions, Inquiry - three questions, and Skepticism - three questions. These questions can be referenced in detail in Appendix B.

3.6.2 Survey Reliability and Validity

Romine and colleagues (2017) developed and validated the Quantitative SSR Assessment (QuASSR) tool that could be used for larger sample sizes. It is a 10-item survey, forced choice dichotomous scale (Yes/No) measure of the SSR construct related to SSI for college students. The QuASRR is a Rasch validated measure (M_{Infit} = 0.80-1.24, M_{Outfit} = 0.74-1.33, Rasch Reliability = 0.82) (Romine et al., 2017). Although the evaluation tool has proved successful in measuring SSR, most literature shows that students do not typically make substantial improvements in any SSR competence in short SSI interventions (i.e one week or few weeks). Significant educational time and a purposeful focus on Vision II scientific literacy are therefore recommended for students to develop SSR in response to SSI instruction (Romine et al., 2017).

I will present three SSI scenarios in this work: first, the genetically modified organism (GMO) issue; second, Global Warming; and third, the vaccine controversy. My decision to use three SSI scenarios to the study reflects the fact that multiple measures in the same study to support the validity of the assessment (Creswell & Creswell, 2017). These scenarios are based on previous SSR measurement work (Sadler and Zeidler, 2009; Sadler et al., 2011; Romine et al., 2017). The assessment instrument was reviewed by two biology education professors, and revisions were made according to the comments from the reviewers. Students will require approximately 30 minutes completing each scenario at each time point. These SSI scenarios and questionnaires are presented in the supplementary materials. The early drafts of scenarios were reviewed by science researchers and educators. A copy was also sent out to the instructor of the class. Feedback involved clarifying jargon, disambiguating phrases, eradicating redundancy, and adding understandable terms related to the science unit.

3.6.3 Content Knowledge Assessment:

In order to assess student content knowledge related to each science unit, the summative tests will be administered following the final day of instruction of each unit. Those assessments contain 40 item multiple-choice tests of covered topics. It is a 50-minute, timed test. It was developed by the instructor who has more than 15-year teaching experience in the same major. The students' responses will be scored by the scan machine at the Assessment Resource Center, University of Missouri-Columbia and placed on the report forms along with the students' summative tests.

Tests are designed to assess a student's knowledge of science concepts and principles that a student taking this class should possess. The questions include not only conceptual comprehension but also the use of these principles in specific problems when content knowledge is involved. For instance, in the genetic unit exam, one question is '*On March 12, LiveScience (and many other news sources) posted a story that explained Scott Kelly returned "after a year in space with big changes to his genetic code, so much so that he was no longer his brother's identical twin." Based on of what you know about gene expression, this is...?*' Students who grasp the concept should solve the problem and should be able to select the correct answer.

The 40 questions of each test will be coded using the cognitive process dimension of the revised Bloom's taxonomy suggested by Krathwohl (2002). The cognitive process dimension includes the categories "remember," "understand," "apply," "analyze," "evaluate," and "create" (Krathwohl, 2002). As a means to validate the categorization of content knowledge (low and high order cognitive processes), an inter-rater reliability (IRR) will be calculated. I will work with another researcher in the science education field to code 10% of the content knowledge questions. If we feel that the question is a straightforward recall question and does not require connecting several pieces of information together, these questions will be assigned to the *lower-order* cognition process subset questions group. Questions not answered by merely recalling the information in the textbook or lectures will be considered *higher-order* questions (Bloom et al., 1956; Lemons & Lemons, 2013). These questions include the identification and evaluation of evidence, the drawing up of existing information, the suggestion for a solution and the computational analysis to be applied to an unknown situation, and a reasoned justification to be given for the answer. An inter-rater reliability (IRR) will be calculated by using Kappa statistics. If the inter-rater consistency is lower 0.8, we will meet together to negotiate those discrepancies and refining the interpretations until we can get a higher agreement.

3.6.4 Personal Interest:

To measure students' personal interest in SSI, I created a 5-item measure aligned with each SSI scenario, in which participants indicate their level of interest by rating each item on a 5-point Likert-type scale ranging (*1 = Very Uninterested, 2 = Somewhat Uninterested, 3 = Uncertain, 4 = Somewhat Interested, 5 = Very Interested*). This measure of student's personal interest is developed using validated item structures from Feist (2012), Strømsø, Bråten & Britt (2010), and Kitchen and colleagues (2007). The items not only cover a broad range of potential interest-related psychological states while engaging with an SSI subject, but also include *cognitive dimensions* (e.g. interest in understanding the scientific knowledge behind the controversies; interest in understanding the societal perspectives behind the controversies) and *behavioral dimensions* (e.g. interest in negotiating potentially solutions for the controversies regarding GMOs; interest in pursuing an in-depth project related to GMOs). This means that the interest measuring items relate to many different aspects of the Hidi and Renningers' (2006) interest framework rather than simply asking if they are interested in the topic (See Appendix A, B, and C at the Personal Interest Surveys).

3.7 Statistical Methods and Analytic Procedures:

The research questions, null hypothesis, and data analysis shown below:

Research Question	**Null hypothesis**	**Data Analysis**
RQ1: How do SSR competencies vary across scenario contexts?	H_o1: There are no significant differences between SSR competencies performed in three scenarios.	Repeated Measures ANOVA
RQ2: How do SSR sub-dimension competencies relate to one another? Do these relationships vary across scenario contexts?	H_o2: There are no significant correlations between SSR competencies performed in three scenarios.	Pearson's Correlations, Repeated Measures ANOVA

Q3: How does content knowledge and personal interest influence on SSR competencies?	H_o3-1: There is no significant correlation between SSR competencies and content knowledge as demonstrated in high and low-order level.	Pearson's Correlations
	H_o3-2: There are no significant correlations between SSR competencies and personal interest.	Pearson's Correlations
	H_o3-3: The proposed model of interaction between content knowledge, personal interest, and SSR competencies fit the empirical data.	SEM

I plan to use a mixture of quantitative techniques. Five types of analysis are proposed for this study. Results of each analysis inform later analysis and the results of subsequent sections.

First, in order to provide a summary of the sample from which the data is obtained, a summary of the SSR competencies, content knowledge and personal interest as well as the means, modes, range, and standard deviations will be provided.

Second, to determine any differences in SSR competencies according to the moderating effects of individual SSR scenarios, repeated-measures analysis of variance (ANOVA) will be used to look for any significant differences among dependent variables. Repeated-measures ANOVA is used where at least two independent variables are involved in the sample and the same unchanged variables are consistently measured. This technique is appropriate for complex studies with several variables and treatments where each independent variable is repeatedly evaluated with the same participants divided into groups (Field, 2013).

Third, to determine the relationship between four SSR dimensions, *Pearson* product moment correlation coefficients will be determined. Relationships will be tested at the 95% confidence level using Pearson's correlation which controlled for testing instance. The technique will allow to explore how these constructs are associated when the evaluations are carried out.

Fourth, to estimate multiple correlated variables both dependent (SSR) and independent (content knowledge and personal interest) simultaneously in a single analysis, structural equation modeling (SEM) will be used. For the purposes of this analysis, the SEM method is selected as one of the statistical modeling strategies for two reasons: (1) the usage of latent variables and the control of endogeneity. Latent variables are unobserved variables constructed by indicators. In this proposal, latent variables are well suited for SSR research because SSR is considered as a conceptual framework and unobserved directly. The SEM technique will allow for various indicators (i.e., four SSR dimensions) to construct a latent variable (SSR) representing competency. (2) the SEM technique also allows for the specification of directions of relationships between variables. Several studies have used regression analysis to explore the relationship between single dependent and several independent variables. However, regression analysis usually has two main limitations: 1) Regression models are not relational or are additive. 2) Measurement errors are not taken to account (Keith, 2014).

Before starting the SEM analysis, normality of the variables will be tested. If skewness values, kurtosis values, and the histograms of the observed variables do not violate the normality assumption, the further analysis will be processed. Although SEM can be a useful technique to analyze structured relationship between a set of variables, some assumption should be required. If data is no-normal and the sample size is small, I plan to use Partial Least Square SEM (PLS-SEM). This approach is well adapted for circumstances where (1) prediction is emphasized over theoretical study and (2) the criteria for larger samples or the determination of causal factors in SEM are difficult to satisfy (Klind, 2015, p. 360).

3.7.1 The Measurement Models:

In this study, the SSR and Content Knowledge measures will be treated as latent variables in non-nested measurement models. Every model will have a different set of indicators. For example, Model A measures are given as determinants of SSR competencies in four SSR measures in **Figure 2**. The four measures are Complexity, Perspective Taking, Inquiry, and Skepticism. These measures are essential indicators in defining the framework of SSR. The latent variable (SSR) error variance (e5) is set to one for model identification. This implies that the variables of the SSR predictor are the only ones indicated in the model.

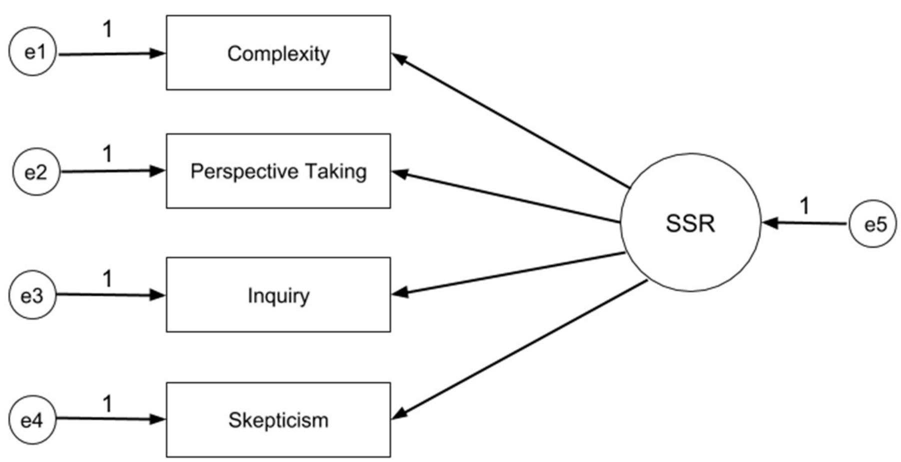


***Figure 2**. Measurement Model A*

In **Figure 3**, the Content Knowledge model has two indicators. The first indicator, Low Cognitive Process, will be measured in students' scores on the unit exam in terms of low order cognition level. The second indicator, High Cognitive Process, is another measure of content knowledge specific to high order cognition level. As Bloom and colleagues (1956) described taxonomy of knowledge and cognition in which cognitive patterns are classified qualitatively into lower and higher order cognition, I want to use this taxonomy for classifying the content knowledge items to ensure a wide range of cognition was embedded within each level. Again, a couple assumptions will be made to identify models. The error variances (e1 and e2) in the indicators are set to one. The error variance (e3) for the latent variable Content Knowledge is also set to one.

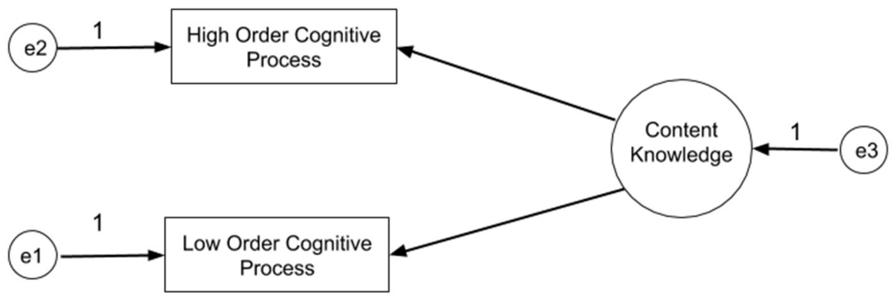


Figure 3*. Measurement Model B*

According to the literature, influence of student's interest towards cognition has been discussed in theoretical and empirical studies (Ainley et al., 2002; Hidi, 1990; Renninger et al., 2014; Schiefele, 1999). Particularly, learners' interest in the subject has an importance as it relates to how they engage and succeed in science learning (Krapp et al., 2004; Schiefele et al., 1992; Potvin & Hasni, 2014). In addition, content knowledge is considered as a factor that can contribute to students' reasoning and decision making (Hogan, 2002; Levine Rose & Calabrese Barton, 2012; Lewis & Leach, 2006; Keselman et al., 2007; Sadler & Fowler, 2006, Yang & Anderson, 2003). Thus, based on theoretical assumptions and prior research, in this proposal I would like to look at the interaction of content knowledge and personal interest to student's SSR. The **Figure 4** shows a tentative model that envelops all components of interest in this proposal.

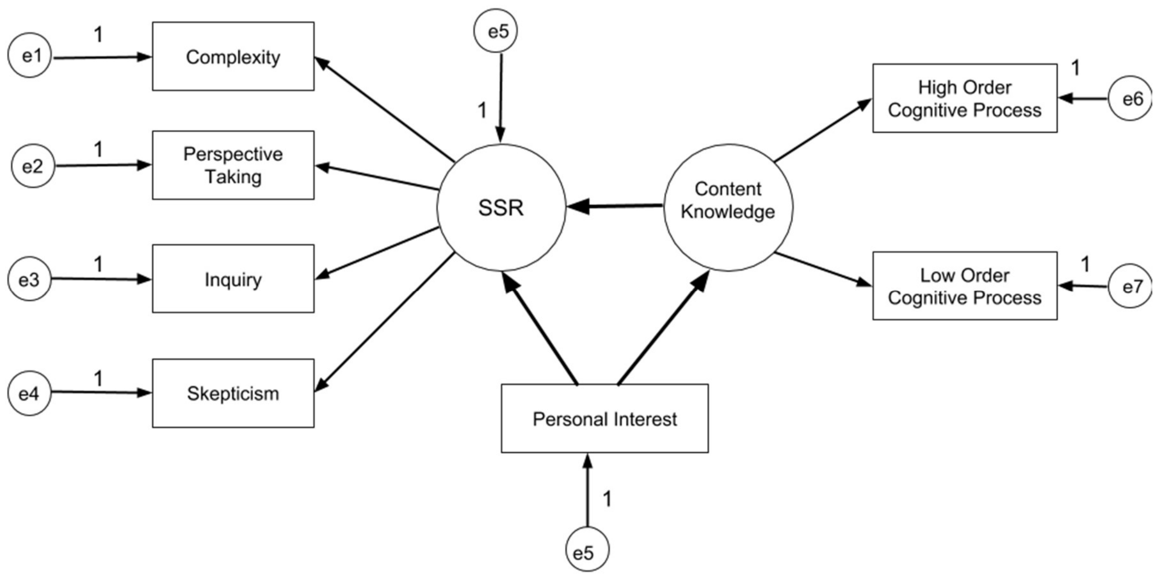


Figure 4. *Model of possible relationship between SSR, content knowledge, and personal interest*

3.7.2 Strengths of the study

There are several strengths associated with the proposal. First, this proposal is grounded strongly in SSI. This theoretical background served to guide the inquiry and inform the findings. Additionally, the conceptual framework of this proposal, the SSR construct, allows the study to build on previous research and guide future research in the student development of SSR. Together, these two strengths answered recent calls by Romine et al. (2017) and Kinslow et al. (2018) that asked for more research that explores the complex relationship within SSR, and between SSR and cognition, and interest. The authors argued that SSR needs not only an understanding of content knowledge but also a connection to students' emotions and cultural values. Second, this proposal features three different SSI scenarios, while also uncovering students' content knowledge and personal interest. Combining methods, including using a validated QuASSR instrument and an SEM analysis, will allow researchers gain deeper insights of relationships of the interested variables and reduce scenario-based bias. Third, the proposal design allows for conclusions to be drawn about how four dimensions of SSR interact and how SSR can be related to content knowledge and personal interest in unique ways.

3.7.3 Limitations of the study

This research is constrained by many factors. The summative test is assumed as an accurate measure of an individual's knowledge about science, but it does not include the specific item scores which can address distal and proximal content knowledge related to the SSR scenario. The data are collected at three time points according to three different topics. Each topic or SSI scenario may invoke certain context or connect with students' previous knowledge which may favor a production of different reactions. Thus, it may be necessary to assign students to more than one scenario during the course. However, providing more scenarios (beyond three) would be not necessary for students' responses regarding time consume (Romine et al., 2017). Some researcher argued that the amount of content knowledge used may change across different biological issues (Grace & Ratcliffe, 2002) and school levels (Sadler & Fowler, 2006), then the relationship between reasoning and content knowledge understanding could also change. While the alpha coefficient, also known as the Cronbach's alpha, indicates an average covariance between two pairs of items in the student sample, the variance in the total score is limited. Since students have different interests in science, it is desirable to consider the accuracy of the instrument in determining the personal interests of students in particular contexts.

Summary

This chapter contained an explanation of the problem, purpose, research questions, research design, research questions, and methodology. The data collection and instrumentation were also described. The purpose of this study is to explore and examine the relationship, if any, among SSR scores and the number of core content knowledge learned by undergraduate students in one general biology course. For statistical analyses and quantitative inquiries, I design the analysis to achieve internal and external validity. In order to distinguish variations in participants' output in three SSI contexts between their assigned groups and between groups of participants, the data will be analyzed using repeated-measures ANOVA models. The statistical tests will help to reveal whether there will be an interaction and dependency among the factors. Consequently, an initial measurement model including two independent latent constructs (content knowledge and personal interest), one dependent measured variable (SSR) is depicted in Figure 4. A SEM approach then will be employed since this technique can help to evaluate how well a hypothesized conceptual model fits its associated data. The focus of this study is to determine if there are any correlations among SSR, content knowledge, and personal interest and how the directions of those relationships can be represented. The chapter also justified the usage of mix of quantitative techniques to clarify those relationships.

CHAPTER 4 – RESULTS

4.1 Introduction

In this chapter, the results of analyses will be concisely presented. First, descriptive statistics among variables will be provided. Secondly, to assess the concurrent relationships among the four sub-dimensions of the SSR construct, Content Knowledge, and Personal Interest, the results of several statistical tests conducted on the sample will be delivered. Thirdly, given potential influences of Content Knowledge and Personal Interest on students' SSR competencies, structural equation modeling (SEM) will be tested and reported. Through these three sets of information, the results of the research questions presented in chapter one will be presented. The chapter also will conclude with a summary of key findings.

4.2 Descriptive Statistics

The data were checked for missing values, univariate outliers, multivariate outliers, and violation of assumptions. Of the 212 cases that were collected for the study, only 130 cases met criteria; and 82 cases were excluded from further analysis since they did not complete all three SSI scenarios. According to the histograms, skewness, and kurtosis statistics, the variables were normally distributed. No missing data was found in the final sample of 130 cases. These numbers reveal the distribution of the SSR, Content Knowledge, and Personal Interest variables are approximate to a normal distribution. Descriptive statistics for all SSR variables in the data set are presented in Table 6. There were three SSI scenarios reported: Global Warming, Genetically Modified Organisms (GMO), and Vaccinations.

***Table 6**. Descriptive Statistics for SSR sub-dimension competencies in three SSI scenarios*

	Global Warming		GMO		Vaccinations	
	M	SD	M	SD	M	SD
Complexity	2.72	1.03	2.74	.89	3.03	.85
Perspective-taking	2.12	1.16	2.06	1.11	2.66	1.15
Inquiry	2.80	1.41	2.91	1.59	3.28	1.47
Skepticism	2.63	1.51	2.77	1.54	2.90	1.63
SSR Total	10.27	1.27	10.48	1.28	11.87	1.26
High-Order Content Knowledge	14.07	8.67	20.67	6.34	24.17	9.75
Low-Order Content Knowledge	43.37	21.15	50.09	13.85	51.20	11.28
Personal Interest	17.50	3.38	17.23	2.15	18.42	3.36

4.3 SSR sub-dimension competencies

Research Question 1. *How do SSR sub-dimension competencies relate to one another? Do these relationships vary across scenario contexts*?

In order to address the research question 1, *Pearson*'s correlation analyses were conducted to measure the strength of the relationship between SSR sub-dimension competencies in each SSI scenario context. In each context of SSI, a correlation matrix was established to allow examination of associations between SSR sub-dimension competencies. In order to evaluate the magnitude and statistical significance of the six associations between Complexity, Perspective-taking, Inquiry, and Skepticism, each correlation coefficient and its associated *p*-value was examined.

Table 7*. Reliability estimates and inter-correlations among study variables in Global Warming scenario*

Variable	1.	2.	3.	4.
1. Complexity	(.91)	-.017	.459**	.305**
2. Perspective-taking	-.017	(.93)	-.070	.101
3. Inquiry	.459**	-.070	(.90)	.389**
4. Skepticism	.305**	.101	.389**	(.88)

Note: Internal consistency reliability estimates (Cronbach's α) are shown in the diagonal. *$p < .05$, **$p < .01$, and $N = 130$.

In Global Warming scenario, the results showed that Complexity was associated in a positive direction with Inquiry and Skepticism (respectively, $r = 0.459$, $p < 0.01$ and $r = 0.305$, $p < 0.01$). In addition, Inquiry also was significantly related to Skepticism ($r = 0.389$, $p < 0.01$). Notably, the results indicated a strong relationship between Complexity and Inquiry.

Table 8*. Reliability estimates and inter-correlations among study variables in GMO scenario*

Variable	1.	2.	3.	4.
1. Complexity	(.92)	.275**	.416**	.252**
2. Perspective-taking	.275**	(.94)	.322**	.271**
3. Inquiry	.416**	322**	(.91)	.185
4. Skepticism	.252**	.271**	.185	(.90)

Note: Internal consistency reliability estimates (Cronbach's α) are shown in the diagonal. *$p < .05$, **$p < .01$, and $N = 130$.

In GMO scenario, these results indicated that except Skepticism was not associated with the Inquiry, while other SSR sub-dimensions were related to each other at different levels. Complexity was significantly correlated in a positive direction with Perspective-taking ($r = .275$, $p < 0.01$), Inquiry ($r = .416$, $p < 0.01$), and Skepticism ($r = .252$, $p < 0.01$). Perspective-taking also was significantly associated with Inquiry ($r = .322$, $p < 0.01$) and Skepticism ($r = .271$, $p < 0.01$).

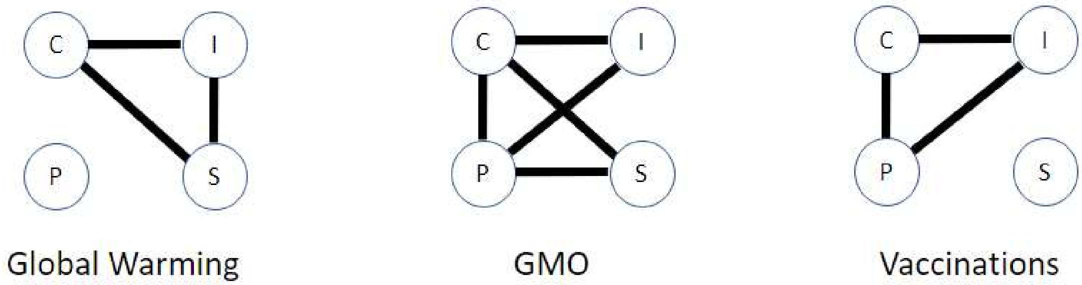
Table 9. Reliability estimates and inter-correlations among study variables in Vaccinations scenario

Variable	1.	2.	3.	4.
1. Complexity	(.87)	.319**	.251**	.036
2. Perspective-taking	.319**	(.89)	.272**	.153
3. Inquiry	.251**	.272**	(.92)	.109
4. Skepticism	.036	153	.109	(.91)

Note: Internal consistency reliability estimates (Cronbach's α) are shown in the diagonal. *$p < .05$, **$p < .01$, and $N = 130$.

In Vaccinations scenario, Complexity was positively correlated with Perspective-taking ($r = .319$, $p < 0.01$) and associated with Inquiry ($r = .251$, $p < 0.01$) while Perspective-taking also was correlated with Inquiry ($r = .272$, $p < 0.01$). These results indicated that except Skepticism was not associated with the other one, all three sub-dimensions including Complexity, Perspective-taking, and Inquiry were correlated together in the Vaccinations issue. The results show that four SSR sub-dimensions are linked in different levels and generate dynamic patterns across the context of scenarios (see Figure 5).

Figure 5. Dynamic patterns of SSR sub-dimension relatedness across three SSI scenarios



Abbreviation Note: C: Complexity; P: Perspective-taking; I: Inquiry; S: Skepticism
The lines represent the significant relatedness among SSR sub-dimensions found from this study.

4.4 SSR competencies, Content Knowledge, and Personal Interest

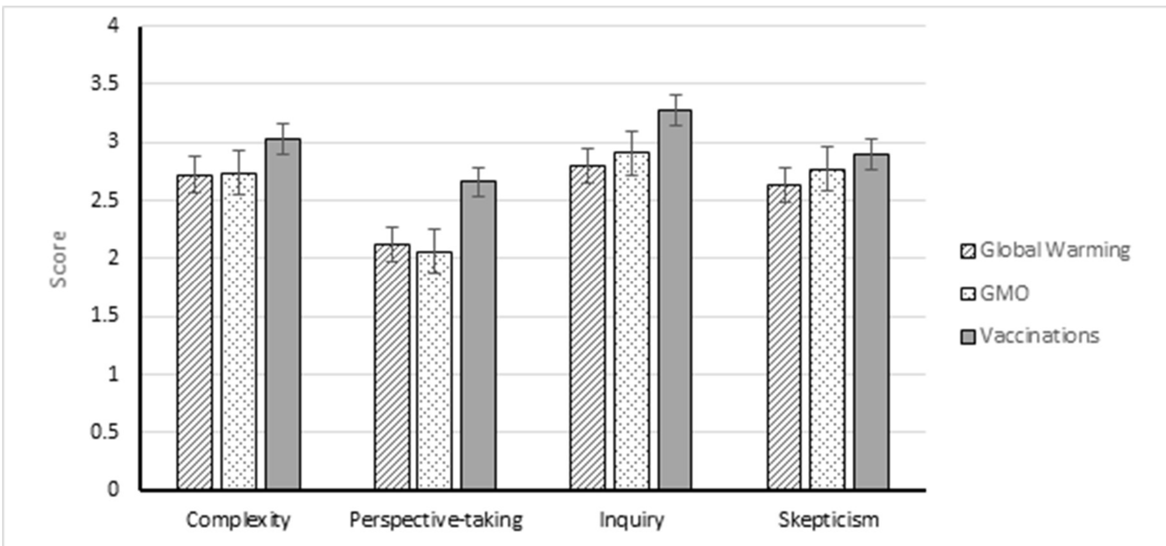
Research Question 2: *How do SSR competencies, Content Knowledge, and Personal Interest vary across scenario contexts?*

4.4.1 Variation of SSR competencies across scenarios

Hypothesis 2a: There are significant differences in SSR competencies measures occurred across the scenario contexts.

In order to address the research question 2, a repeated-measures analysis of variance (ANOVA) was used. Partial eta squared (η^2) was used to calculate the effect size for repeated-measures ANOVA effects. Results revealed a significant main effect of SSI context on SSR competencies, $F(2, 127) = 27.71$, $p < .001$, $\eta^2 = 0.28$ demonstrating that SSR competencies were different across three different scenarios. That means SSR can be affected by when the SSI context is changed. Post-hoc Bonferroni tests were used to examine significant effects in each pair of scenarios and the effect sizes of the Cohen's d(d) were used for all post-hoc pair comparisons. Cohen's ds between 0.20 and 0.50 indicate a small impact size, Cohen ds between 0.50 and 0.80 indicate a medium effect, and ds greater than 0.80 indicate a large effect (Cohen, 1988). As shown in Figure 6 and Table 10, the different SSR competencies existed in the scenario contexts.

***Figure 6**. Distribution of means of students' SSR across 3 scenarios*



Post-hoc tests using the Bonferroni correction to control for inflated Type I error showed that revealed that except Skepticism, other SSR competencies during the Vaccinations scenario were higher than those gaining in the Global Warming and GMO scenarios. Students' SSR competencies in Global Warming and GMO scenarios did not differ from each other ($p = 0.21$, $d = 0.06$)

- **Complexity:**

When comparing students' Complexity competency at each scenario, no differences were found at between Global Warming and GMO scenarios (p = 0.364, d = 0.08), however Vaccinations displayed higher levels of Complexity compared to Global Warming and GMO scenarios (respectively, p = 0.018, d = 0.41; p = 0.010, d = 0.32).

- **Perspective-taking:**

Post hoc comparison indicated that students gained Perspective-taking competency significantly higher on Vaccination scenario compared to Global Warming ($p < 0.000$, $d = 0.58$) and GMO scenarios ($p < 0.000$, $d = 0.65$). There was no difference in students' Perspective-taking competency between Global Warming and GMO scenarios.

- **Inquiry:**

Post hoc tests with Bonferroni adjustment revealed that there were statistically significant differences between Vaccinations scenario compared to Global Warming ($p < 0.000$, $d = 0.61$) and GMO scenarios ($p < 0.001$, $d = 0.57$) on students' Inquiry competency. It was also evident that there was no difference between Global Warming and GMO scenarios on this students' competency.

- **Skepticism:**

It was found that there was no significant difference between SSI scenarios on students' Skepticism.

***Table 10**. Bonferroni Post Hoc Testing Results for SSR Competencies Comparisons per Scenario*

Comparisons of SSR Competencies Between Scenarios	Mean Difference Between Scenarios	Standard Error	*p*-value	Effect size (d)
Complexity				
Global Warming compared to GMO	-0.02	0.016	0.364	0.08
Global Warming compared to Vaccinations	-0.31*	0.021	0.018	0.41
GMO compared to Vaccinations	-0.29*	0.023	0.010	0.32
Perspective-taking				
Global Warming compared to GMO	0.06	0.011	0.260	0.06
Global Warming compared to Vaccinations	-0.54**	0.018	0.000	0.58
GMO compared to Vaccinations	-0.60**	0.020	0.000	0.65
Inquiry				
Global Warming compared to GMO	-0.11	0.017	0.150	0.11
Global Warming compared to Vaccinations	-0.48**	0.021	0.000	0.61
GMO compared to Vaccinations	-0.37**	0.012	0.001	0.57
Skepticism				
Global Warming compared to GMO	-0.14	0.011	0.062	0.14
Global Warming compared to Vaccinations	-0.27	0.014	0.067	0.17
GMO compared to Vaccinations	-0.13	0.012	0.074	0.09

4.4.2 Variations of Content Knowledge across scenarios

Hypothesis 2b: There are significant differences in Content Knowledge measures occurred across the scenario contexts.

Results also revealed a significant difference of Content Knowledge across three scenarios in both Low-Order and High-Order Levels (respectively, $F(2, 127) = 126.56$, $p < .001$, $\eta^2 = 0.31$; $F(2, 127) = 153.48$, $p < .001$, $\eta^2 = 0.27$). The subsequent Bonferroni *Post Hoc* analyses indicated that the

students engaged in GMO and Vaccinations scenarios achieved higher scores in Low-Order Content Knowledge than Global Warming scenario, as shown in Table 11. Significant mean differences were also discovered across three SSI scenarios in students' Higher Content Knowledge. On average, students showed gaining more High-Order Content Knowledge in Vaccination scenario than either Global Warming ($p < .001$, $d = 0.82$) or GMO ($p < .001$, $d = 0.21$) scenarios. In addition, I observed the ratio of higher-order content knowledge per lower-order content knowledge in the Vaccinations scenario significantly higher than Global Warming or GMO scenarios (0.47; 0.32; and 0.41, respectively)

Table 11*. Bonferroni Post Hoc Testing Results for Content Knowledge Comparisons per Scenario*

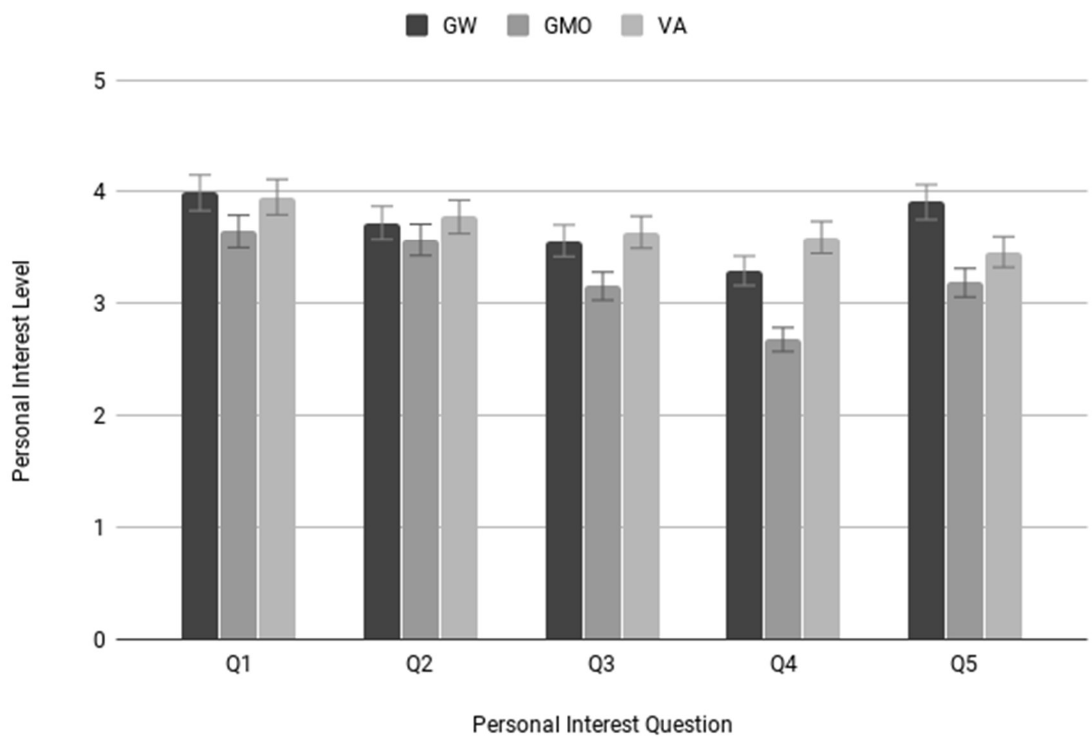
Comparisons Between Scenarios	Mean Difference Between Scenarios	Standard Error	*p*-value	Effect size (*d*)
Low-Order Content Knowledge				
Global Warming compared to GMO	-6.72**	0.260	0.000	0.63
Global Warming compared to Vaccinations	-7.83**	0.325	0.000	0.59
GMO compared to Vaccinations	-1.11	0.184	0.052	0.18
High-Order Content Knowledge				
Global Warming compared to GMO	-6.60**	0.298	0.001	0.75
Global Warming compared to Vaccinations	-10.1**	0.442	0.000	0.82
GMO compared to Vaccinations	-3.50*	0.268	0.023	0.21

* $p < 0.05$; ** $p < 0.001$, two-tailed.

4.4.3 Variation of Students' Personal Interest across Scenarios

Hypothesis 2c: There are significant differences in Personal Interest measures occurred across the scenario contexts. Bonferroni post hoc test were used to determine which scenarios engage most students' Personal Interests.

***Figure** 7. Differences in Personal Interest measures occurred across the scenario contexts.*



Results of *post-hoc* Bonferroni analyses adjusted paired *t*-tests showed that students considered significantly less interested in GMO as compared to Global Warming (GW) and Vaccinations (VA) for the following 3 reasons of interest: Scientific Knowledge ($M_{GW\text{-}GMO} = 0.34$, $d = 0.27$; $M_{VA\text{-}GMO} = 0.30$, $d = 0.35$), Potential Solutions ($M_{GW\text{-}GMO} = 0.40$, $d = 0.54$; $M_{VA\text{-}GMO} = 0.48$, $d = 0.59$)

and Stakeholder's Perspectives ($M_{GW\text{-}GMO}$ = 0.61; d = 0.43; $M_{VA\text{-}GMO}$ = 0.91, d = 0.71) (Figure 7, Table 12). There was no statistically significant difference among SSI scenarios regarding students' Personal Interest in Societal Perspectives. However, students showed that they were very interested in potential projects related to the Global Warming issue than either GMO ($M_{GW\text{-}GMO}$ = 0.72; d = 0.86) or Vaccination ($M_{GW\text{-}VA}$ = 0.44; d = 0.68).

Table 12. *Bonferroni Post Hoc Testing Results for Personal Interest Comparisons per Scenario*

Comparisons of Personal Interest Between Scenarios	**Mean Difference Between Scenarios**	**Standard Error**	***p*-value**	**Effect size (*d*)**
Question 1 - Scientific Knowledge				
GM compared to GMO	0.34*	0.009	0.049	0.27
GM compared to VA	0.03	0.004	0.098	0.18
GMO compared to VA	-0.30*	0.014	0.040	0.35
Question 2 – Societal Perspectives				
GM compared to GMO	0.15	0.013	0.165	0.12
GM compared to VA	-0.05	0.007	0.125	0.09
GMO compared to VA	-0.20	0.034	0.055	0.27
Question 3 – Potential Solutions				
GM compared to GMO	0.40**	0.029	0.001	0.54
GM compared to VA	-0.07	0.015	0.068	0.32
GMO compared to VA	-0.48**	0.038	0.000	0.59
Question 4 – Stakeholders' Perspectives				
GM compared to GMO	0.61**	0.056	0.001	0.43
GM compared to VA	-0.30*	0.028	0.038	0.62
GMO compared to VA	-0.91**	0.082	0.000	0.71
Question 5 – Related Projects				
GM compared to GMO	0.72**	0.042	0.000	0.86
GM compared to VA	0.44**	0.017	0.000	0.68
GMO compared to VA	-0.27	0.036	0.059	0.34

Note: GM: Global Warming Scenario; GMO: Genetically Modified Organisms Scenario; VA; $*p < .05$, $**p < .01$

4.4.4 Content Knowledge and Personal Interest influence on SSR competencies

Research Question 3: How does Content Knowledge and Personal Interest influence on SSR competencies?

From this research question, I predicted High-Order Content Knowledge would be positively related to SSR (Hypothesis 3a) and increases in SSR competencies would be associated with increases in students' Personal Interest in SSI (Hypothesis 3B).

To assess potential influences of Content Knowledge and Personal Interest on SSR competencies, bivariate correlations were run across the variables and the scenarios (see Table 13). The results showed that there were some associations between SSR and Content Knowledge and Personal Interest across three scenarios. Of particular note, Low-Order Content Knowledge was significant related to changes in SSR competencies over the scenarios. In order to better understand the relationship between the variables, a structural analysis was conducted.

***Table 13**. Correlations between SSR competencies (total scores) and Content Knowledge and Personal Interest demonstrated in three different scenarios*

	Global Warming	GMO	Vaccinations
High-Order CK	0.24	0.17	0.46*
Low-Order CK	0.35*	0.47*	0.67**
Personal interest	0.34**	0.24	0.54**

Note: CK: Content Knowledge; *$p < .05$, **$p < .01$

Structural equation modeling (SEM)

A SEM analysis requires that the measurement model be tested before any structural models can be evaluated. In this study, the maximum likelihood estimation method was used in order to confirm the proposed hypotheses.

Measurement Model

The first confirmatory factor analysis (CFA) using maximum likelihood estimation was conducted. The measurement model consisted of 3 main latent constructs: Students' SSR, Personal Interest, and Content Knowledge. Because three different scenarios of factor structures were obtained, the models were examined separately. For each scenario, Initially, CFA was used to determine if our hypothesized model fit the data properly. Structural model analysis has been performed on the estimation of the CFA model. According to the CFA, the best fit indices (*RMSEA* = .051; *NFI* = .97; *CFI* = .98) indicated that the estimated covariances of the hypothesized model were similar to the covariances found in the study. In addition, since the chi-square difference between the CFA models was significant ($\chi^2 = 1792.65$, $df = 127$, $p < .001$), it appears that the models were identified in terms of linking SSR to Content Knowledge and Personal Interest. The chi-square tests showed significant differences between the models and the data in the three scenarios ($\chi^2 = 988.09$, $df = 127$, $p < .001$ for the Global Warming scenario model, $\chi^2 = 1051.41$, $df = 127$, $p < .001$ for the GMO scenario model, and $\chi^2 = 1238.65$, $df = 127$, $p < .001$ for the Vaccinations scenario model). Thus, these three models were reasonable for uncovering the relationships in our theoretical models. Since the CFA models showed a strong model fit through three scenarios, the path analysis will be used to analyze the relationship between the variables as well as the significance of the proposed model. The results of path analysis were showed in Table 14.

***Table 14**. SEM Model Regression Weights*

Paths in the model	Standardized Parameter Estimate (β)		
	Global Warming	GMO	Vaccinations
Personal Interest → SSR	0.325*	0.751**	0.482*
Personal Interest → Content Knowledge	0.165	0.682**	0.575*
Content Knowledge → SSR	0.221	0.424*	0.314

Note: *$p < 0.05$; **$p < 0.01$

Figures 8, 9, and 10 illustrate the results of the models in three different SSI contexts with estimated path coefficients.

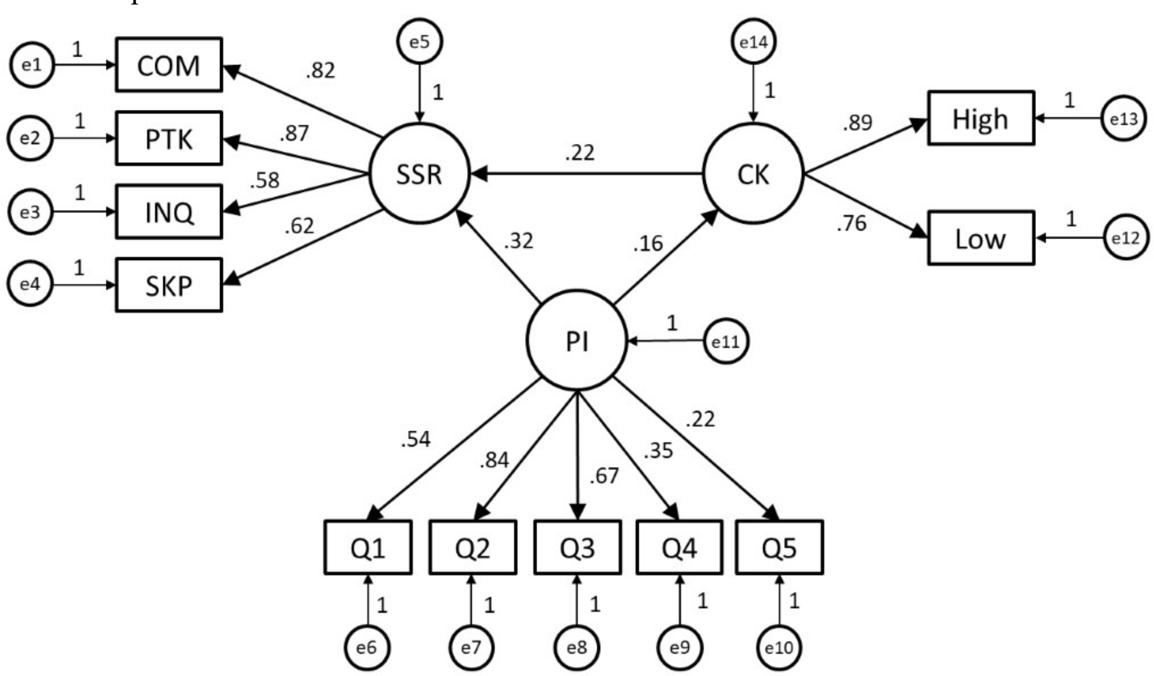


***Figure 8**. The SEM Model Fit in Global Warming scenario*

Notes: COM: Complexity; PTK: Perspective-Taking; INQ: Inquiry; SKP: Skepticism; SSR: Socio-Scientific Reasoning; CK: Content Knowledge; PI: Personal Interest; Q1-Q5: Question 1 - Question 5. Circles imply latent variables, rectangles are observed variables, and the numbers in the small circles shown by the observed variables are residual variances. The numbers in the small circles that point to the latent variables are disturbance variances and are set to one. Standardized loading factor is shown in the arrow lines above.

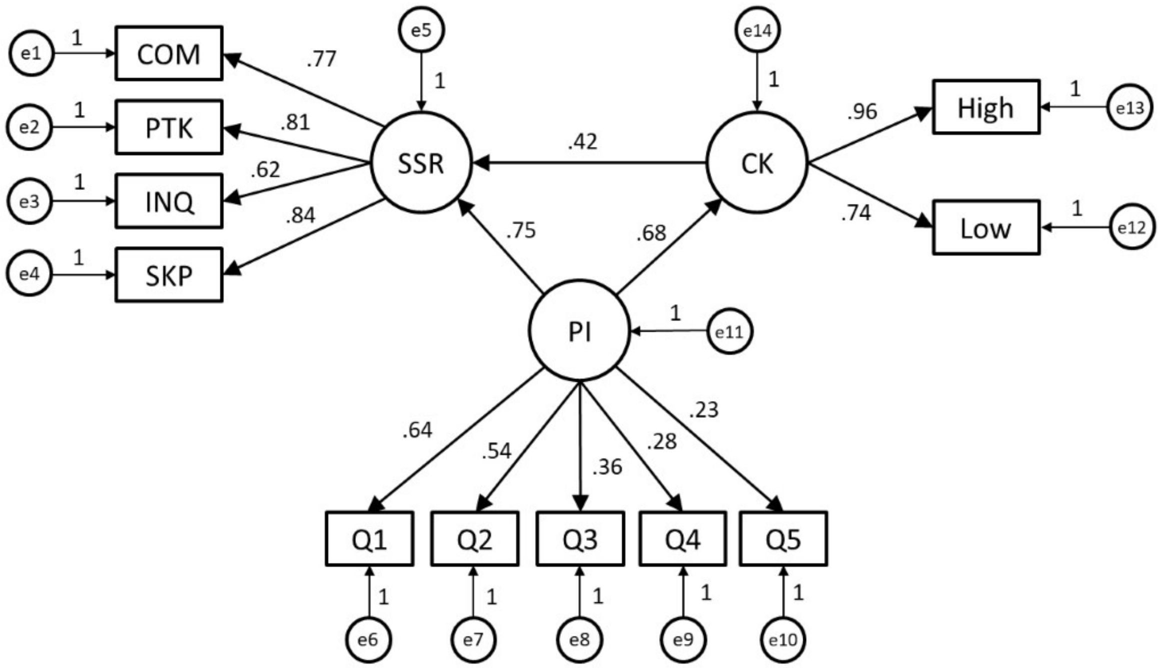


***Figure 9**. The SEM Model Fit in GMO scenario*

Notes: COM: Complexity; PTK: Perspective-Taking; INQ: Inquiry; SKP: Skepticism; SSR: Socio-Scientific Reasoning; CK: Content Knowledge; PI: Personal Interest; Q1-Q5: Question 1 - Question 5. Circles imply latent variables, rectangles are observed variables, and the numbers in the small circles shown by the observed variables are residual variances. The numbers in the small circles that point to the latent variables are disturbance variances and are set to one. Standardized loading factor is shown in the arrow lines above.

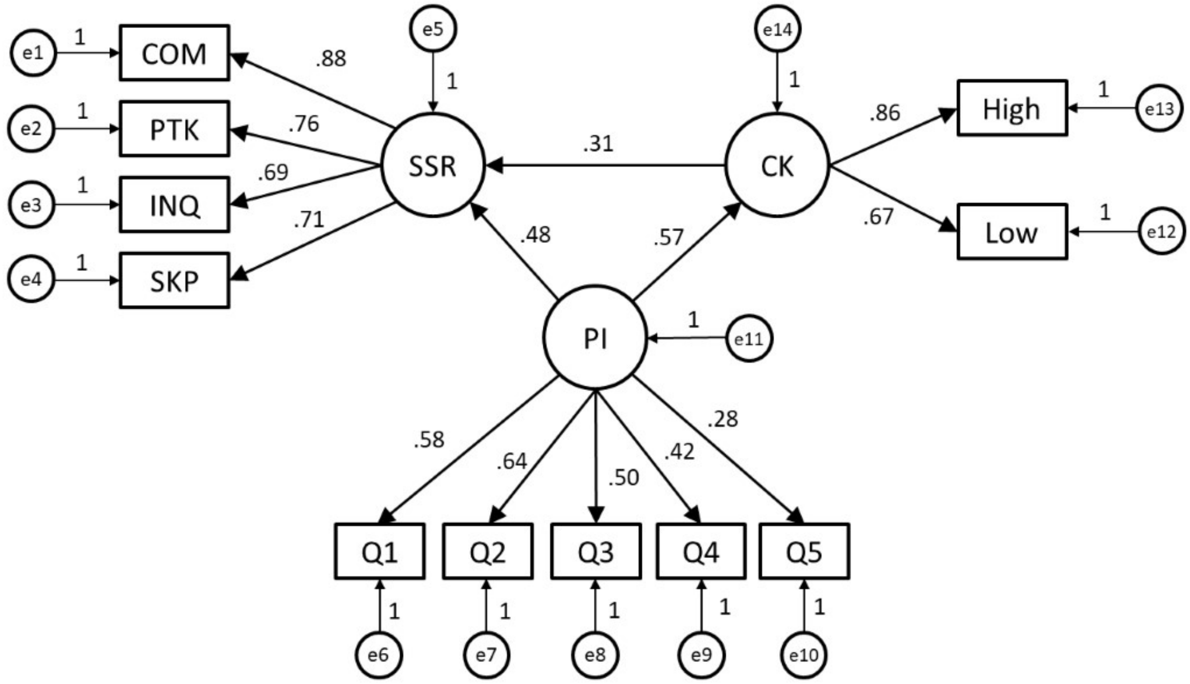


***Figure 10**. The SEM Model Fit in Vaccinations scenario*

Notes: COM: Complexity; PTK: Perspective-Taking; INQ: Inquiry; SKP: Skepticism; SSR: Socio-Scientific Reasoning; CK: Content Knowledge; PI: Personal Interest; Q1-Q5: Question 1 - Question 5. Circles imply latent variables, rectangles are observed variables, and the numbers in the small circles shown by the observed variables are residual variances. The numbers in the small circles that point to the latent variables are disturbance variances and are set to one. Standardized loading factor is shown in the arrow lines above.

Synthesis of SEM findings across scenarios

Hypothesis 3a (H3a) addressed relationship among students' Content Knowledge and their SSR competencies. It was hypothesized that higher cognition in Content Knowledge associated with SSR competencies. Findings of the study (Table 13) showed low associations between Content Knowledge and SSR across three scenarios ($\beta = 0.221$, $p > 0.05$ for Global Warming scenario; $\beta = 0.424$, $p < 0.05$ for GMO scenario; $\beta = 0.314$, $p > 0.05$ for Vaccinations scenario). Thus, H3a was not supported (Table 14).

Hypothesis 3b (H3b) proposed an effect of students' Personal Interest on students' SSR competencies. It was hypothesized that students' Personal Interest positively influenced students' SSR. Results in Table 14 indicated that students' Personal Interest did have a significant positive effect on students' SSR across three scenarios ($\beta = 0.325$, $p < 0.05$ for Global Warming scenario; $\beta = 0.751$, $p < 0.01$ for GMO scenario; $\beta = 0.482$, $p < 0.05$ for Vaccinations scenario), thus supporting Hypothesis 3a. According to Kline (2005), the values of standardized path coefficients reaching approximately .30 can be interpreted as a "typical" or medium influence. More than .50 will have a large effect. Personal interest may therefore have a major impact on the increase in students' SSR. H3b was therefore supported (Table 14).

***Table 15**. The Model Fit Hypotheses and Test Results*

Hypothesis	**Result**
H3a: The higher students understand science content knowledge, the more SSR competencies will be developed	Not supported
H3b: The more students are interest in the SSI, the more SSR competencies will be developed	Supported

4.6 Summary of the Key Findings

Three main findings were summarized in accordance with the research questions as follows:

Firstly, some students' SSR sub-dimension competencies were correlated to each other within the SSI scenario, but those associations were not consistent across the scenarios. This finding suggests that SSR is a dynamic multi-dimensional construct.

Secondly, there were significant differences in SSR competencies measures occurred across the scenario contexts. Students gained SSR competencies greater in the Vaccinations scenario than in the Global Warming and GMO scenarios.

Lastly, given the goodness-of-fit statistics, the proposed models showed the effects of Personal Interest on SSR. The level of Personal Interest in the SSI might have a large effect on the increasing level of SSR. In contrast, the SSR competencies were not significantly influenced by Content Knowledge across three scenarios.

CHAPTER 5 – DISCUSSION

5.1 Review of Purpose of Study

The purpose of this study was to explore the relationships between SSR and Content Knowledge and Personal Interest as undergraduate students engage in a series of SSI scenarios. The study was guided by the assumption that there are influences of Content Knowledge and Personal Interest on students' SSR competencies. While elements of SSR construct have been examined in prior research (e.g., Kinslow et al., 2019; Romine et al., 2017; Sadler et al., 2011), at this point, there has been very little empirical quantitative research examining the relatedness of key elements of the SSR construct, particularly in concert with Content Knowledge and Personal Interest as students engage with SSI. The results of the analysis revealed that students' SSR varied across three different SSI scenarios. The analysis also revealed that as a confluence of cognitive and affective domains, students' SSR change across three SSI scenarios, in which lower Content Knowledge and Personal Interest have a significant impact. In the following section, I will discuss these findings considering the reviewed literature. The discussion is organized around the three areas that covered the study, specifically, 1) Relatedness of SSR sub-dimensions, 2) SSR sub-dimension variation, 3) Influence of Content Knowledge, 4) Influence of Personal Interest. The section also discusses the implication of research and future study regarding empirical evidence and limitations.

5.2 Discussion of the Findings

5.2.1. Relatedness of SSR sub-dimensions:

SSR construct is defined as a conceptual framework that includes four reasoning sub-dimensions: Complexity, Perspective-taking, Inquiry, and Skepticism (Sadler et al., 2007). The results of the analysis of the students' SSR competencies revealed that there were significant correlations between sub-dimensions within each SSI scenario. This means that the reasoning outcome an individual experiences while negotiating an SSI is not solely a dimension of the SSR construct but is interactive between the four sub-dimensions. Some researchers have investigated quantitatively the associations between SSR sub-dimensions (Irmak, 2020; Owens et al., 2019a; Romine et al., 2017; Sadler et al., 2007). For example, Irmak (2020) found the significant relations between Complexity, Perspective-taking, and Inquiry as students negotiate fracking issues. Particularly, in the original SSR research, the correlations associated with complexity and inquiry were relatively high, while other associations were low (Sadler et al., 2007). However, in a follow-up study, Sadler et al. (2011) found no significant inter-dimensional associations within SSR construct as students engaged in a global climate change issue. Our results, however, reveal the dynamic relationship between the sub-dimensions across SSI scenarios.

Although researchers agree that SSR is conceptualized as a multifaceted construct, relatively few studies examine the relatedness of SSR sub-dimensions across multiple scenarios. Our findings show that SSR sub-dimensions relatedness exists, but it seems flexible. That means SSR is a multi-dimensional construct, and all sub-dimensions are related to each other and change the level of relatedness across SSI scenarios. Indeed, using a Rasch model to analyze the items within the SSR construct, Romine et al., 2017 noted that "*each of these items, if used alone, may bias the students' measures by approximately one standard error*" (p.16). Taken together, I suggest that even if SSR is a multi-dimensional construct, it should be treated as a consistent framework with coherent in each dimension. These interacting sub-dimensions which may influence and may be influenced by each other integrate in dynamic ways and determine a student's reasoning regarding SSI.

As I view SSR as a dynamic construct rather than a static construct, I recognize all sub-dimensions relatedness can be varied across SSI scenarios. A dynamic view of the SSR construct should provide greater insight into the facets associated with perceptions of SSR, especially because a number of researchers have suggested that the four-dimension SSR construct may not capture the richness of individuals' reasoning experience (Kahn & Zeidler, 2016; Karahan & Roehrig, 2017; Owens et al., 2019a; Sakschewski et al., 2014; Simonneaux & Simonneaux, 2009). These researchers suggested additional considerations of SSR sub-dimensions. For example, affordances of science and non-science considerations represent recognition of ways that "*science can and cannot account for natural phenomena associated with SSI, and the extent that science, as compared with other considerations such as sociocultural factors and ethical commitments"* (Owens et al., 2019a, p.27). While it is understandable that the number of SSR sub-dimensions will be extended in future as more qualitative and interdisciplinary research is employed, perhaps the SSR sub-dimensions relatedness will not remain stable during a series of SSI learning. What should be noted is that an SSR scenario is introduced to individuals within ongoing *dynamic* relationships, not to isolated reasoning dimensions separately. As such, assessment of an individual's SSR should be understood as capturing patterns of relationships within the construct that sub-dimensions interact.

Unidimensional measures of SSR may enable researchers to accurately assess the overall level of SSR competencies of a person, while multidimensional measures may allow researchers to evaluate the specific contributions and implications of each dimension for the development of SSR. Compared with the single sub-dimension of SSR, overall SSR scores can provide more accurate, parsimonious, and consistent results regarding how students gain their reasoning experience through SSI learning. Because the SSR sub-dimensions are usually tightly linked as the findings of this and previous studies, a student's reasoning experience might depend on an overall SSR performance throughout the SSI scenario (Romine et al., 2017). As such, overall SSR scores might offer greater predictive power than specific SSR sub-dimensions when the sub-dimensions are relatively limited in nature. Another potential issue with the multi-dimensional SSR construct measurements is that meta-analyzes are challenging if the equivalence of extended SSR sub-dimensions is not tested. Although I appreciate a multi-dimensional conceptualization of SSR that is empirically valid and other sub-dimensions may be added in future, I argue that an overall score of SSR provides a better fitting explanation of students' reasoning experience. In this study, consequently, I employed overall SSR scores as a measure to analyze their relationship with Personal Interest and Content Knowledge.

5.2.2 SSR sub-dimensions variation:

The results of the analysis of undergraduate students revealed that they recognized and considered the multiplicity of dimensions that exist within SSI as they were making efforts to resolve a series of SSI scenarios. Specifically, the analysis of the Complexity dimension across three SSI scenarios revealed that students were more prone to recognize the complex characteristics of the SSI. Indeed, the Complexity component belongs to the nature of SSI as Zeidler and Sadler (2011) elaborated that SSI is complex as its definition. One reason for the Complexity component designed in the first part of the questionnaire may relate to the fact that the QuASSR is designed as a scaffold to facilitate students explore

SSI insights and develop their reasoning, in which the easier tasks related to Complexity dimensions are introduced at the beginning of the assessment. For instance, Romine et al. (2017) stated that Complexity in the QuASSR serves as "*a logical starting point for building students' SSR*" (p.17). In addition, perhaps having extensive experience with SSI learning, along with progression of SSR, the Complexity dimension becomes more accessible in the follow-up issues.

Exploring the Perspective-taking dimension across three SSI scenarios revealed that this aspect was lower as compared with other dimensions, except in Vaccinations scenario. The findings suggest when students faced with the health issue students were likely to think about alternative perspectives. This finding is consistent with previous findings in the literature regarding the multiple perspectives. Cian (2020a) compared students' perspective components between environmental issue and gene therapy issue, and she found that students gained higher score on the gene therapy topic. That reflects students feel easier to develop reasoning towards ability to describe the different opinions involving in the health issue. "Perspective-taking" as a dimension of SSR refers to the negotiation of SSI from different perspectives (Zeidler & Sadler, 2011). Recognition of other perspectives is considered an important part of a good argument (Kahn & Zeidler, 2019). Authors expressed that SSI involve dilemmas that prioritize conflicting ideas, points of view, and values.

For Inquiry dimension, our result revealed that undergraduate students were competent in identifying the needs of ongoing investigation in all three SSI scenarios. Inquiry dimension of SSR was elaborated based on the uncertain nature of SSI (Sadler et al., 2007). Due to all three SSI scenarios (Global Warming, Genetically Modified Organisms, and Vaccinations) being intentionally designed as contemporary ill-structured problems, the information presented in the text may not be sufficient or may be biased. These limitations of scientific sources and situations of uncertainty, even conflicting data, force students to consider the need for seeking additional information as well as ongoing investigation. This observation is consistent with the literature on Inquiry perspective in SSR assessment for both pre-service teachers as well as students who engage in SSI learning (Irmak, 2020; Kinslow et al., 2019; Owens et al., 2019a; Sadler et al., 2011; Sadler et al., 2011; Topcu et al., 2010).

The analysis of SSR sub-dimensions also revealed that students gained Skepticism competency in all three scenarios. While students' Complexity, Perspective-taking, and Inquiry competencies were statistically significantly higher in the third SSI scenario (Vaccinations), there was no significant difference in Skepticism competency as compared between three SSI scenarios. These findings are consistent with the findings in the literature that skepticism may be harder to achieve in a short course (Kinslow, 2018). For example, Kinslow (2018) described the students' challenges in achieving the dimension of skepticism regarding the local proposal of an ethanol plant after engaging in a six-week SSI-oriented field ecology class. In order to cultivate skepticism, students need to practice skeptical thought (Karahan and Roehrig, 2017) and carefully examine media reports for potential bias (Owens et al., 2019a). Similarly, using the same QuASSR assessment, Irmak (2020) found that college students' Skepticism competency was the lowest score in all dimensions of SSR. These studies highlight the difficulty of gaining skepticism throughout the SSI scenarios. These similarities support the conclusion that Skepticism often comes with varied information or suspending judgment until sufficient information is available (Kinslow et al., 2019; Owens et al., 2019a; Romine et al., 2017). In short, the results of the present study demonstrate a variation of SSR sub-dimensions across three scenarios. Students seem more prone to consider multiple perspectives with health safety topics related to their generation (e.g., Vaccinations), but they struggle with recognizing bias information in terms of Skepticism dimension.

The instrument of reasoning measure used can influence students' performance, interpretations, and the overall understanding of nature of SSI. To meet the goals of our study, I used four-dimensional SSR to explore their interactions. The original conceptualization in the construct maybe well suited for a single scenario, but it is hard to fully capture with a series of SSI scenarios along semester as students employ many different resources and diverse topics and many of them would have different values regarding the quality of information. Like the dimension of Skepticism, I feel that it is necessary to explain some nuanced features of perspective-taking. Perspective-taking was defined as “able to examine an issue from multiple perspectives” (Sadler et al., 2007, p. 381) or “consideration of diverse and often opposing scientific and non-scientific view-points" (Owens et al., 2019a, p. 3), we must consider that some students might consider moral or emotive perspectives in negotiation of SSI. Kahn and Zeidler (2019) suggested that Perspective-taking should have a meaning “*that a student shifts their positionality, or viewpoint, to that of another person in order to analyze a SSI, which is essentially a contextualized moral dilemma*” (p. 629). Newton & Zeidler (2020), recently, have reported that students’ perspective-taking can be improved via a series of scaffolded learning experiences such as sociocultural reading, writing, meeting with stakeholders. Thus, whatever the perspective-taking, clarifying the stakeholders in each SSI will be helpful for students’ negotiation as they are working on complex and contemporary issues.

5.2.3. Influence of Content Knowledge on SSR

Many scholars have arguments, based on both theoretical and empirical perspectives, for the claim of reasoning skills (including but not limit as critical thinking, informal reasoning, higher-order thinking, reflective thinking, scientific reasoning) are influenced by understandings of Content Knowledge (Baytelman et al., 2020; Davut Gul & Akcay, 2020; Ennis, 1989; Karahan & Roehrig, 2017;

Sadler & Zeidler, 2005a). As SSR construct is viewed as an informal reasoning practice that captures outcomes of SSI learning for science literacy, it is necessary to elucidate the relationship between Content Knowledge and SSR. Efforts to unfold the relationship between SSR-like variables and Content Knowledge tend to be assessed on quantitative research. Content Knowledge is often measured on the simple tests or multiple-choice surveys, in which the subjects are requested to assess students' understanding in certain domain-specific knowledge. It is, however, often doubtful which exact level or type of Content Knowledge is really assessed in a range of cognition. Thus, there is a need to specify Content Knowledge sub-categories measure that can be helpful for teachers and/or educators to assess students' understanding about the science unit related to SSI. In this present study, I employed two categories of Content Knowledge (Low-Order and High-Order Content Knowledge) based on Bloom's revised Taxonomy (Anderson et al., 2001). Content Knowledge as a cognitive domain that emphasizes on knowledge understanding (Lower-order Content Knowledge) and transferring (Higher-order Content Knowledge) as the participant attempts to resolve SSI.

The results show that there are some positive correlations between scientific Content Knowledge and reasoning, particularly Low-Order Content Knowledge measured in each unit which is aligned with the specific SSI, was statistically significantly related to SSR competencies. This finding suggests that students who understand the basic scientific ideas also negotiate the SSI in the most multi-faceted manner. Our results are in line with other studies that have concluded that the basic knowledge can support students' reasoning, including informal reasoning (e.g., Hogan, 2002; Rose & Barton, 2012; Lewis & Leach, 2006; Keselman et al., 2007; Sadler & Fowler, 2006; Villarín & Fowler, 2019). Researchers believe that greater understanding of the SSI may necessitate a higher gain in relevant Content Knowledge (e.g., Dori et al., 2003; Sadler et al., 2011; Zohar & Nemet, 2002). In contrast, Sadler and Zeidler (2005) observed that the students with the highest levels of Content Knowledge were able to make stronger arguments. Similarly, Liu et al. (2011) found that undergraduate students studying science showed the Content Knowledge related to the issues throughout the argumentation process. However, it is important to note that these studies examining Content Knowledge associated with argumentation did not classify the level of Content Knowledge based on any taxonomy. These high levels of Content Knowledge were simply assessed based on the total score of tests or qualitatively evaluated based on students' discourse, in which that may include a high portion of Low-Order Content Knowledge.

While students negotiate SSI, they can engage in various forms of informal reasoning such as argumentation, decision-making process, critical thinking. Among those SSR-like variables, argumentation has been regarded as an effective means to access students' informal reasoning. However, the result contrast to previous studies related to argumentation that show students rarely refer science Content Knowledge in their reasoning while engaging in SSI (Dawson & Venville, 2009; Karahan & Roehrig, 2016; Morin et al., 2014; Sadler and Donnelly, 2006; Yang & Anderson, 2010). They found that students tend to rely more heavily on ethical, feelings, societal, or economic factor rather than on scientific information. Similarly, Wu and Tsai (2007) found that students usually struggle to connect what they had learned in science classrooms with the relevant SSI they encountered. However, the relationship between levels of Content Knowledge and SSR competencies should be explored further and not to presume the existence of linear relationships.

As Higher-Order Content Knowledge was termed for analyzing, synthesizing, and evaluating of cognitive domain, I expected Higher-Order Content Knowledge would have an impact on SSR competencies. Surprisingly, I found no evidence in two first SSI scenarios (Global Warming and GMO), except the last one (Vaccinations). There are several possible explanations based on literature that are discussed below: different mechanisms underlying Content Knowledge levels; different development of skills in reasoning; and different abilities to organize and connect Lower-Order Content Knowledge for issue resolution.

First, there seem to be different mechanisms underlying Content Knowledge levels. One of them can be interpreted as the relationship between Content Knowledge and SSR might not vary linearly. Lower-Order Content Knowledge can support for students build the foundations for attaining higher-order content knowledge, in turn it then can stimulate thinking skills such as problem solving and decision making (Domin, 1999; Newmann, 1991; Griffin et al., 2009; Fensham & Bellocchi, 2013). However, Zoller & Tsaparlis (1997) found that high school students' performances in lower and higher-order content knowledge have different patterns and they were not necessarily correlated to each other. Specifically, the authors found that gaining a high score in the lower-order content knowledge did not guarantee a good performance on the higher-order content knowledge (Zoller & Tsaparlis, 1997). Thus, many educators suggest that a balanced structure of lower- and higher-order content knowledge in instructions as well as assessments would contribute to improving students reasoning skills (Espedal, 2008; Fensham & Bellocchi, 2013).

Second, students would not be able to develop reasoning skills, reflective skills, and higher-order thinking as the first time they expose to the complex and controversial problems (Battista, 1999). Instead, they may have spent most of their time familiarizing themselves with the first SSI scenario (Global Warming). Indeed, in our study I found that there was a statistically significant association between Higher-Order Content Knowledge with SSR competencies in the last SSI scenario (Vaccinations) after they had been introduced to two previous ones (Global Warming and GMO). Moreover, overall SSR scores in the Vaccination scenario were observed higher than others. Scholars have noted that SSR is a difficult competence that students can gain in a short unit (Romine et al., 2017; Sadler, Romine, et al., 2016). Particularly, the ability to consider multiple perspectives and skepticism require students to use other science practices and epistemic tools (Chang et al., 2020; Ke et al., 2020; Kinslow et al., 2019). Science educators indicated that long-term implementation of SSR improvements could be needed (Sadler et al., 2011). Several studies also show the need for intensive and long-term intervention to the growth of higher-level cognitive skills (Dori, Tal & Tsaushu, 2003).

Third, a further explanation might be that even though students gain certain higher-order content knowledge in two first SSI scenarios, they could have difficulty to organize and connect to their lower-order understanding of science ideas to resolve the issues. Correspondingly, Wu (2013) reported that students who gained and used better-organized content knowledge structures tended to achieve higher informal reasoning quality. In our study, the content knowledge structures were not assessed in detail, but I observed the ratio of higher-order content knowledge score per lower-order content knowledge score as an observable measure reflecting the distribution of content knowledge that students achieve in science topic units. The results showed that the ratio of higher-order content knowledge per lower-order content knowledge in the Vaccinations scenario significantly higher than Global Warming or GMO scenarios. This finding revealed that students with more portion of sophisticated higher-order content knowledge, which is assumed being constructed and organized, in the entire assessed content knowledge were more oriented towards SSR; and the higher-order content knowledge per se is not the sole factor of successful informal reasoning. These findings are consistent with previous research that found the in-depth content knowledge might not always constitute a sufficient condition for the development of critical thinking skills (Ennis, 1989).

Understanding of key concepts within the topic would have the positive impact on their reasoning. This observation may provide encouragement to teachers who believe that their explanations of foundational concepts and terms before they explore details are critical for science lessons, as reported by other studies (Eggert et al., 2017; Irmak, 2020; Lee et al., 2008). This is an interesting direction for future study to further investigate what aspects of Content Knowledge (e.g., proximal and distal knowledge, domain-specific and domain-general knowledge) students usually employ to resolve complex issues. Sociocultural factors (e.g., morals, beliefs, ethics, and values) should also be considered (Herman, 2015; Zeidler, 2016). Baytelman and colleagues (2020) also suggested that students' epistemic beliefs and prior knowledge may predict students' argumentation skills. It seems reasonable to believe that Content

Knowledge has complicated relations with SSR development. This argument could explain why we need to clarify different levels of Content Knowledge, thereby specifying the effect of the Content Knowledge factor.

5.2.4. Influence of Personal Interest on SSR

Personal Interest Differentiation:

While Content Knowledge provides existing information regarding how SSI related natural phenomena, the resolution for an SSI might be reflected through human choices. Zeidler portrays that "*SSI is, de facto, connected to the quality of personal choices about community and global issues*" (Zeidler, 2020, p. xix). In fact, science is limited in several ways to find a successful resolution in complex interests among citizens living in society. Therefore, it necessarily requires considerations of sociocultural and emotive factors. As shown in Table 6, the data revealed that in general students have different interests in SSI. Students showed Personal Interest greater in the Vaccinations scenario than in the Global Warming and GMO scenarios. In other words, students would be more interested in exploring personal health novelty as they find those issues are relevant to their ages. This result is also consistent with the findings obtained in science topics related to nuclear power plants and human-induced climate change as researchers examined students' interest toward their attitude (Stenseth et al., 2016). Students prefer to explore health protection issues related to nuclear power plants than global impacts related to climate change. In other studies, some researchers have also recognized the differences of Personal Interest in a variety of science topics. For instance, Sullivan (1979) found that there are differential patterns of change in students' interest for certain science topics across-grade levels. Particularly, Gedrovics et al. (2010) investigated 1065 students for 5 years period and found that students' interests were comparatively higher in personal health topics and problems in nature. Their students also showed their Personal Interest in physics and biology higher than chemistry problems. Although it seems that it is impossible to know exactly why and how students have different interests, it assumes that students' Personal Interest may be influenced by their backgrounds such as beliefs, and family background, personality, past experiences, and prior knowledge.

In this present study, I found that students largely achieve their SSR along with their Personal Interest in the SSI. In other words, students who hold stronger Personal Interest in SSI exhibited stronger overall SSR competencies. Specifically, as shown in Table 13, Personal Interests significantly predicted SSR competencies across three scenarios. As such interesting results, Personal Interests loaded significantly on the overall SSR scores across three SSI scenarios, as well as the overall Content Knowledge factors (except Global Warming scenario). The results further demonstrated that the Personal Interest items related to science behind the issues and societal perspectives were the strongest predictors of SSR competencies. Thus, the results of our study stress the importance of considering the domain of interests in SSR research. Consistent with theoretical frameworks explaining the origin of Personal Interest, researchers suggest that Personal Interest have multidimensions including affective, cognitive, and behavioral components (Draijer et al., 2020; Krapp & Prenzel, 2011; Rotgans & Schmidt, 2017). Personal Interest items used in this study were designed to cover three those components. Interestingly, the most interest level across three SSI scenarios was identified at cognitive components in Personal Interest questionnaires (e.g., interest in scientific knowledge, interest in societal perspectives). Those items asked students to quantify their interest with respect to knowledge as they want to understand science and societal perspectives behind the SSI better. In contrast, students show less interest in affective components (e.g., stakeholder's opinions) and behavioral components (e.g., participating in projects). That reflects students wanting to explore the science behind each SSI. This state of mind could be defined as "*self-determined inquiry*" as mentioned in previous studies (Jack & Lin, 2017).

One of possible reasons for different interests on different SSI topics is the novelty associated with text content. The contemporary interest theory (Hidi, 1990) distinguishes two types of interest regarding their characteristics as in-the-moment engagement or as enduring engagement. In contrast, Silvia (2006) proposed the perception and apperception of appraisals as identifying experience of interest. In his position, primary appraisal is a decision as to whether an object is deserving of further consideration, while secondary appraisal require evaluation of the value of the object or case. Regarding SSI as an ill-structured problem that connects scientific and societal perspectives, I believe that Personal Interest may be drawn on the uncertainty and/or multi-faceted issue in nature as it unusually is presented in traditional science classes.

In turn, this interest domain might have a large effect on the SSR development. Many of the studies of interest in science learning showed that Personal Interest can be a predictor of learning (e.g., Renninger, Hidi, & Krapp, 2014; Schiefele, 1999; Tobias, 1994). However, the relationship between Personal Interest and SSR or SSR-like variables has not been investigated rigorously. Our model explained the impact of Personal Interest on students' SSR competencies, which is similar to finding from other studies on critical thinking (e.g., Carroll, 2007; Gul, & Akcay, 2019) and reasoning (Endicott, Bock, & Narvaez, 2003). Some studies have found associations between students' personnel interests and their position on SSI (e.g., Kardash&Whyell, 2000, Murphy & Alexander, 2004; Sinatra, Kartash, Taasoobshirazi, & Lombardy, 2012). For instance, Sinatra et al. (2012) found that the personal interest of undergraduates in their "*willingness to take mitigative action*" (p.4) was strongly associated with climate change attitudes. However, a study by Kahan et al. (2012) indicated that personal interest and topic awareness could exert influence on determining people's attitudes towards SSI such as climate change. Many studies suggest small reciprocal effects between interest and content knowledge, but the causal relationship data are still inconclusive (Rotgans & Schmidt, 2017).

In Global warming and GMO scenario, students' Personal Interests were less pronounced in the present study because they would not consider this issue very concerning or "hot trending" given the popularity of GM food in the country. It is consistent with the model of Petty and Wegener (1999), which notes that the motivation of development of attitudes decreases as problems are regarded as less significant. Due to the lack of motivation, a student may easily decide to judge based solely on his or her prior experience. Conversely, students' Personal Interests were observed higher in Vaccinations scenario. It can be explained that the issue would be more interesting as it challenges students think about "a heroin vaccine" that prevents addiction in young people increasingly today. Indeed, Vaccinations scenario offers content related to multiple disciplines including biology, psychology, sociology, ethics, and so on. These areas may ask students to draw on not only their personal experience but also their existing knowledge. That may contribute to their students' reasoning in breadth and depth, so that eventually they are better at recognizing the complexity, multiple perspectives, and the needs for ongoing inquiry in SSI.

Students could address a more concrete scenario where the students may have a more Personal Interest. The sense of interest includes positive activation (affect), directed attention and desire for action (motivation), and inquiry for knowledge (cognition) (Hidi & Ann Renninger, 2006; Hidi & Harackiewicz, 2000). Personal Interest may promote students to learn more about a topic, contributing to improved concentration, focused attention, and a desire to learn. (Hidi & Renninger, 2006). I have observed that recent attention has been paid to SSI resolutions, which individuals seldom draw on scientific understandings (Sadler, 2004; Sadler & Donnelly, 2006; Wu & Tsai, 2007). I also note that few people relate the content of SSI and their decisions (Zohar & Nemet, 2002). This observation connects to relevant Content Knowledge within students' experience, which Zeidler and colleagues (2018) assert promote science literacy. Rotgans and Schmidt (2017) proposed a model in which growing Personal Interest is a result of knowledge gain.

SSR competencies represent thinking skills and intellectual ability (e.g., identify the multiple perspectives, recognize the bias information) over a certain period within the SSI education. Thus, Personal Interest may be stronger related to such personal traits or constant skills compared to performance at a single occasion such as taking a test. Assuming a series of science curriculum-related SSI scenarios that more closely reflect the interest of students would show higher relationships to SSR competencies. It may be speculated that the students with high interest in SSI might demonstrate a "curiosity" nature in that it was likely to be intertwined with basic science understanding (Ainley et al., 2002; Hidi & Harackiewicz, 2000). It might be possible that the students with high Personal Interest and high Content Knowledge understanding are more likely to develop SSR. Interest and SSR seem characterized the same with multidimensional construct, in which require both cognitive and effective domains (Hidi, Renninger, & Krapp, 2004; Sadler et al., 2007; Krapp & Prenzel, 2011). That means a Personal Interest is ready to acquire new topic or content. I believe that Personal Interest is driving force, but it is not an only factor to promote SSR development.

Personal Interest and Accumulation:

Another reason for higher SSR scores in the last SSI scenario (Vaccinations) as compared to two previous ones (Global Warming and GMO) can be assumed as an improvement of practices. Due to practices, SSI negotiation seems a dominant skill among participants in the third scenario. Higher students' SSR competencies were substantially explained by accumulations of SSI practices. As the SSI learning event progressed, the SSR competencies might increase through exploring diverse SSI scenarios, which can be used as meaningful learning tools. This claim is supported in a previous study of SSR-like variables as critical reasoning skills (Keselman et al., 2007). The authors found that students developed and accumulated logical thinking skills over a 4-week intervention with multiple case-study discussions and assessments for students' comprehension of HIV biology (Keselman et al., 2007). SSI learning, furthermore, can be seen as a sequence of learning stages that connect previous experiences in situated learning (Sadler, 2011). The assumption underlying SSI education is that SSI scenarios can evoke students' affective engagement and their reasoning competencies are cumulative across the curriculum (Sadler, 2011; Sadler et al., 2017; Sormunen et al., 2017). However, given that several recent studies have reported the effects of teaching and learning environments on students' SSI reasoning (e.g., Habig et al., 2018; Palmer, 2004; Cian, 2020a), it is important to note that Personal Interest was not sole an affective factor contributing to the SSR competencies of this study. Our results therefore suggest that first attempts of connecting Personal Interest to SSI learning in classrooms is critical and it is possible to result in promoting situational interest during a shorter period. This hypothesis appears to be applicable for investigation of relation of Personal Interest and situation interest along the lesson sequences in further research. Further interest research helps to understand the motivation behind SSI negotiations and how best to promote SSR development in a wide range of educational contexts. Yeager and colleagues (2014) raised a concern that it would be impossible for a teacher to connect every lesson to the "idiosyncratic interest of one student" (p.576). That means when a teacher wants to bring an SSI into his/her class, it would be necessary to find ways to offer students diverse opportunities and times to connect to their interest.

Contexts that support the gradual accumulation of skills offer opportunities for students to formulate productive negotiations view them as science-based issues. Continuous and relevant contexts like these might be helpful for students to practice and develop their skills in which they can explore deeper and provide insights in each dimension of SSR. Previous studies also suggest that students often accumulate their skills as they engage with the same structure or format case study instruction (e.g., Davut Gul & Akcay, 2020; Dawson & Carson, 2017; Maniatakou et al., 2020). Research has also shown that students benefit when they are engaged in SSI instruction for a long period. Further studies document the value of consistent instructions with diversifying the context as science teaching (Asghar et al., 2012; Chang et al., 2020; Hansson et al., 2011). Students whose teachers offer more various SSI had more opportunities to construct explanations, argue from evidence, and communicate their findings. Science teachers and educators agree that science should be taught in schools in a way that makes sense for students and connects to their experience, eventually helping them to make informed decisions. In our study, this includes allowing students to experience various controversial issues, deal with multiple perspectives, negotiate possible solutions that connect to their current learning in the classroom. The findings from the supplementary analysis provide support for those concerned with increasing the connection to students' interest in SSI based on their perception and experience, in which students decide the way how they engage and negotiate the existing information (Arnone et al., 2011; Owens et al., 2019a; Polman & Hope, 2014).

5.3 Implications of the Study

5.3.1 Implications for Science Education Research

Our study is one of the first research to provide evidence for the relationship between Personal Interest and SSR not only within a single SSI topic but also across different SSI topics. In our model, Personal Interest has a significant positive effect on students' SSR across three scenarios ($\beta = 0.325$, $p < 0.05$ for Global Warming scenario; $\beta = 0.751$, $p < 0.01$ for GMO scenario; $\beta = 0.482$, $p < 0.05$ for Vaccinations scenario). This study continues to add to the SSR's literature about how the construct works and interacts with other factors. The study extends existing SSR understanding into a specific relationship with students' Personal Interests. Specifically, research has shown that students possessing a higher Personal Interest in cognitive, affective, and behavioral aspects of SSI topics are more likely to prove high SSR competencies. The findings offer new avenues for science education research in terms of connections of students' interest to the outcomes of SSI learning. This direction could be further elaborated through refined and validated instruments as well as advanced SEM analysis. In addition, the findings contribute to understanding about the connections of hierarchy of content knowledge to students' SSR competencies. This present study suggests Lower-Order Content Knowledge plays an important role for students' SSR. So, it may be fruitful to support students grasp basic concepts and principles related to the science topics or behind the SSI as a prerequisite for SSR development. More research is needed to illuminate the reciprocal relationships between variables used in this study.

5.3.2 Implications for Science Teaching:

Our ultimate goal was to explore students' SSR for the design of SSI instruction and curriculum, and eventually promote functional science literacy. I suggest that science teachers' approaches in SSI teaching as well as their selection of SSI need to consider students' interest and their previous knowledge related to the issue. While the basic science knowledge can definitely play an important role in negotiation of SSI, instructors should also be aware that students' interest and engagement in a topic can often be more important than their prior content knowledge. Personal Interest engagement offers a connection between what students already know and what they want to develop. Therefore, an SSI scenario should be authentic, and it can stimulate self-directed learning. This suggestion allows students to accumulate or acquire their skills to consider the complex sociocultural aspects of the given issues. Relevant and various SSI scenarios throughout semester or school year would be recommended. In addition, Lower-Order Content Knowledge, which focuses on understanding basic scientific principles behind the SSI, may be used as a primer for furthering interests that are basically sociocultural and affective endeavors.

5.3.3 Recommendations for Research

Future study is needed to explore how teachers actively incorporate SSI into their classes with considerations of students' interest as well as Content Knowledge. There are many things I still do not know exactly about how Lower-Order Content Knowledge are related to students' SSR. I suggest further research on structure and function of Content Knowledge since students' understanding and personal experience may often influence their reasoning (Balgopal et al., 2017; Morton et al., 2011, Cian, 2020b). Another significant research direction to pursue is to continue monitoring how students' SSR competencies develop over time. Most SSR research focuses on single intervention and without a control group, which leaves much more room to explore between different groups (i.e. Socioeconomic backgrounds, gender, ages). Future study may involve additional control variables, to see if Personal Interest and Content Knowledge would remain as specific predictors of students' SSR development and/or their reciprocal interaction would occur. Recently, science education researchers suggest an additional dimension to the SSR construct named as "Affordances of science and non-science considerations" (Owens et al., 2019a, p. 3). Future work therefore needs to include this dimension and target various relevant contemporary issues which may offer more levels of interest in this area. Many recommendations above are aligned with recent directions in SSI research (Zeidler, Herman & Sadler, 2019). Recent research suggests that Personal Interest might interact with other activities and educational conditions (Cheung, 2018; Knekta et al., 2020; Rotgans & Schmidt, 2017). However, I was not able to include other variables in educational conditions in this study. Such interaction effects should be further investigated in future research to elucidate how student's benefit most. Since SSI learning can be viewed as a form of situated learning in schools, this can generate situational interest and lead to new personal interests in the content. Thus, how intrinsic and extrinsic sources influence SSR competencies can be a need for future research.

5.4 Limitations of the Study

Like all research, this study has limitations that should be reviewed carefully when interpreting the findings. One constraint is the scope of the student population. As non-science students are the target population, the findings of this study are likely to be different if repeated in a different population of science students with stronger backgrounds and experiences. Another limitation is the lack of demographic details that might provide a clearer understanding of the student's interest when negotiating SSI. Content Knowledge measure was limited by its focus on final session assessments in the course. Including other forms of assessment, such as pretests and formative assessments, may more accurately capture the differences across levels of cognition. For example, Cian (2020b) has recently suggested a pre- and post-instrument to assess students' knowledge, values, and personal experiences related to the topic as they negotiate SSI. A limitation of the QuASSR measure was that it was primarily quantitative in nature.

Other affective and social-contextual factors could account for variance in SSR development among participants. Besides, I cannot assume an evidently causal relationship until I must design stronger, better-controlled studies that prove the effect of Personal Interest on the development of students' SSR. The findings did not allow us to draw clear conclusions about the effect of Personal Interest and prior Content Knowledge on SSR competencies. Greater samples are required for further multivariate analysis, such as SEM, which can confirm causal relationships. I expected to find in our study that higher Content Knowledge would be the most interesting factor for SSR development. However, my results do not allow us to identify a significant relationship between Higher-Order Content Knowledge and SSR. In future research a wide variety of SSI scenarios should also be included in order to continue Personal Interest explorations in SSI contexts. I acknowledge that other sociocultural variables and instructional approaches may also contribute to students' SSR development.

5.5 Conclusions

In this study I attempted to examine the extent to which Personal Interest and Content Knowledge were associated with SSR in learning three different biology topics. This study confirmed that students' SSR competencies varied as they negotiated various and relevant SSI such as Global Warming, GMO, and Vaccinations. SSR is a dynamic multi-dimensional construct and helpful for assessing students' informal reasoning. The interaction between Content

Knowledge and students' reasoning is complex and is the need for further exploration. The data analyzed in this study clarified the association of Personal Interest and SSR. The level of Personal Interest in the SSI might have a large effect on the development of SSR. Taken together, the results have shown that Personal Interest played a critical role in determining SSR variation. Thus, I conclude that SSR is an issue-specific multidimensional construct and related to Content Knowledge and Personal Interest. From this perspective, our study suggests that SSI as relevant and meaningful contexts that can trigger Personal Interest as well as support developing Personal Interest along SSI education. If the goal of science education is to prepare students to use their scientific knowledge in their everyday decision-making, an authentic engagement of students in meaningful SSI and a construction of knowledge behind those issues need to be a part of that goal. I encourage science education researchers to adapt SSR construct in their disciplines to gain a deeper understanding of interactions between students' interest, Content Knowledge and SSR competencies across disciplines and to find a better way to support students' success in scientific literacy.

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APPENDICES

Appendix A

Global Warming Scenario:

The Future of Mark Twain National Forest

Mark Twain National Forest is a US National Forest in Missouri's southern region. Some areas in the forest have been routinely cleared to make wood, some other areas have been conserved for recreation, while others have been periodically "thinned" by clearing invasive cedars and restoring glades and grasslands, to minimize the risk of high wildfires.

A private contractor proposes to the Forest Service to build a woody biomass power plant. As being described in the proposal, he will purchase wood biomass extracted from the forest and use it to fuel the power plant. He also says that his solution would minimize gross carbon emissions from the atmosphere. In fact, electricity typically comes from a coal-fired power plant in this region.

Forest Service believes the project benefits everyone because it would raise revenue by selling electricity from the plant and they will have the funds to complete the necessary forest treatments. In a public announcement, they said that the proposition as very ecologically appropriate and will benefit the resources, the wildlife habitat and eventually the scenery. They believe that this idea as an economic boost for the town with new jobs and revenue.

Most rural residents worry that smoke from burns will negatively impact air quality and thus area residents with health conditions who might live downwind and tourists camping or canoeing in the area. George Becker, a retired biologist living in this area, have called for saving Mark Twain National Forest. Responding to the media, he said: "We believe in letting Mother Nature take her course. We don't think that this proposal will lower total carbon emissions to the atmosphere."

Conservationists have recently discovered that the area was originally a far more diverse complex of woodlands and glades. They reported that removing invasive cedars and prescribed burns systematically would restore a healthier forest ecosystem.

Local leaders are trying to decide whether to sign a long-term contract with the bioenergy entrepreneur.

Personal Interest Survey:

How interested are you in ...?

Please check a number to the right of each description, to represent your interest in the corresponding topic.

1 = Very Uninterested
2 = Somewhat Uninterested
3 = Uncertain
4 = Somewhat Interested
5 = Very Interested

	1	2	3	4	5
Understanding the scientific knowledge behind the controversies regarding global warming					
Understanding the societal perspectives behind the controversies regarding global warming					
Negotiating potentially solutions for the controversies regarding global warming					
Evaluating all stakeholders' perspectives regarding global warming					
Pursuing an in-depth project related to global warming					

Multiple Choice Test (Adapted from Romine et al., 2017)

What is your major? ________________________________

I understand that my responses will remain anonymous after the instructor gives credit for the assignment and give consent for my responses to be used in research.

- Yes
- No

SSR DIMENSION: COMPLEXITY

1. Imagine that you are in charge of resolving this issue. Would this be a difficult issue to resolve?
   (A) Yes
   (B) No

If A, then: Select the response below that best explains why the Mark Twain National Forest Bioenergy issue is complex.

- The Mark Twain National Forest Bioenergy issue is complex because it deals with complicated dimensions of ecology and economics. (Score 1 pt)

- The Mark Twain National Forest Bioenergy issue is complex because it presents multiple tradeoffs related to the supply of food and the environment. (Score 2 pts)
- The Mark Twain National Forest Bioenergy issue is complex because we do not know all the consequences (positive and/or negative) of the process. (Score 1 pt)

If B, then: Select the response below that best explains why the Mark Twain National Forest Bioenergy issue is a fairly straightforward issue.

- The Forest Service wants to utilize the woods, and Mark Twain National Forest Bioenergy can lower total carbon emissions. Therefore, Bioenergy is a positive development for our society. (Score 0 pt)
- Smoke from burns of the Mark Twain National Forest Bioenergy plant will negatively impact air quality. Therefore, Bioenergy plant should not be developed. (Score 0 pt)
- Mark Twain National Forest Bioenergy may generate controversies, but science and technology can be used to overcome these potential problems. (Score 0 pt)

2. Can the controversy associated with the building a bioenergy plant using Mark Twain National Forest biomass be resolved easily?

(A) NO
(B) YES

If A, then: Why is the Mark Twain National Forest Bioenergy case difficult to resolve?

- Because it involves balancing environmental concerns, human health, and the economy. (Score 2)
- Because topics like the environment, pollutions, and the economy are complicated. (Score 1)
- Because the description of the case offers limited information. If more details were available, the issue would be easier to resolve. (Score 1)

If B, then: Why is the Mark Twain National Forest Bioenergy case easy to resolve?

- It is clear that bioenergy plant utilizes the left-over woods, and it is also beneficial for the economy; therefore, bioenergy should develop in the Mark Twain National Forest area. (Score 0)
- It is clear that building of bioenergy plant will lead to environmental problems; therefore, bioenergy should be banned. (Score 0)
- Once scientists are able to analyze the complete case, they will be able to create a solution that is fair for all interested parties. (Score 0)

SSR DIMENSION: PERSPECTIVE-TAKING

3. How likely is it that the Forest Service and local residents would endorse the same solution to the Mark Twain National Forest Bioenergy issue?

(A) It is **very likely** that the Forest Service and local residents would endorse the same solution.
(B) It is **NOT very likely** that the Forest Service and local residents would endorse the same solution.

If A, then: Why is it very likely that the Forest Service and local residents would endorse the same solution?

- The two groups will likely collaborate and reach a shared solution. (Score 0)
- If two groups work toward a solution, they will end up with the same basic plan. (Score 0)
- An independent panel of experts could be called in to develop a solution that meets the needs of all interested parties. (Score 0)

If B, then: Why is it not very likely that the Forest Service and local residents would endorse the same solution?

- The Forest Service and local residents have different priorities. (Score 2)
- The Forest Service and local residents have not had enough time to reach consensus. (Score 1)
- The Forest Service and local residents have access to different pieces of information. (Score 1)

4. How likely is it that the Forest Service and environmental activists would endorse the same solution to the Mark Twain National Forest Bioenergy issue?
(A) It is **very likely** that Forest Service and environmental activists would endorse the same solution.
(B) It is **NOT very likely** that Forest Service and environmental activists would endorse the same solution.

If A, then: Why is it very likely that Forest Service and environmental activists would endorse the same solution?

- The two groups will likely collaborate and reach a shared solution. (Score 0)
- If two groups work toward a solution, they will end up with the same basic plan. (Score 0)
- An independent panel of experts could be called in to develop a solution that meets the needs of all interested parties. (Score 0)

If B, then: Why is it not very likely that Forest Service and environmental activists would endorse the same solution?

- The Forest Service and environmental activists have not had enough time to reach consensus. (Score 2)
- The Forest Service and environmental activists have access to different pieces of information. (Score 1)

- The Forest Service and environmental activists have different priorities. (Score 0)

SSR DIMENSION: INQUIRY

5. If you were asked to make a decision on whether to accept or deny the Mark Twain National Forest Bioenergy proposal, do you feel as though you have enough information to make a decision?

(A) **I feel I have sufficient information** to make a decision about whether to accept or deny the Mark Twain National Forest Bioenergy proposal.

(B) **I do NOT feel I have sufficient information** to make a decision about whether to accept or deny the Mark Twain National Forest Bioenergy proposal.

If A, then: Why is there sufficient information to make a decision about whether to accept or deny the Mark Twain National Forest Bioenergy proposal?

- The benefits of developing bioenergy plant outweigh the risks. Building a bioenergy plant using Mark Twain National Forest woods lower total carbon emissions and brings money into the forest management, both of which are important for the Missourian people. (Score 0)
- The risks of bioenergy plant outweigh the potential benefits. Building a bioenergy plant brings smokes and releases other toxic pollutions, both of which will negatively affect the quality of life for the local people. (Score 0)
- Since the research was done independently by the environmentalists, the effects of building a bioenergy plant are clear. (Score 0)

If B, then: Why is there not sufficient information to make a decision about whether to accept or deny the Mark Twain National Forest Bioenergy proposal?

- Everyone has different data. If Forest Service and local residents and environmental activists agree on the proper data and collect it in a nonbiased way, then there will be sufficient information to make a decision. (Score 0)
- It is still unclear whether or not bioenergy plant is causing pollutions and other environmental risks. This needs to be confirmed before a decision can be made. (Score 1)
- I am not sure about the economic and scientific details behind building a bioenergy plant, and thus, I should do more reading before I can make a decision. (Score 2)
- The long-term risks and benefits of bioenergy are unclear and need more study before a decision can be made. (Score 2)

STUDENT'S OPINION

6. If you were forced to make a decision whether to accept or deny the bioenergy proposal based on the information in the article, what decision would you make?

- Accept the bioenergy proposal

- Deny the bioenergy proposal

7. 7. Do you think the Forest Service and local residents and environmental activists would agree with your decision?

(A) I feel all parties **would agree** with my decision.

(B) I feel one or more of the parties **would not agree** with my decision.

If A, then: Why would all parties agree with your decision?

- If all parties looked at the issue without bias, then it is clear that bioenergy is causing more harm than good. (Score 0)
- If all parties looked at the issue without bias, then it is clear that the benefits of bioenergy outweigh the potentially harmful effects. (Score 0)

If B, then: Why would one or more parties likely not agree with your decision?

- Certain parties will disagree because they do not have proper understandings of the risks and benefits of bioenergy. (Score 0)
- It is unlikely that I could get all parties to agree with my decision because their agreement depends on whether or not they are benefitting from bioenergy. (Score 2)
- It is unlikely that all parties would agree at first due to their different perspectives. However, they would eventually come to a common agreement about the best course of action to take. (Score 1)

8. If the decision you made on whether to accept or deny bioenergy proposal were put into action, would you recommend that additional funds and resources be used to continue studying the effect of bioenergy on environment?

(A) I would **NOT recommend** continuing to study the effect of bioenergy on environment.

(B) I would **recommend** continuing to study the effect of bioenergy on environment.

If A, then: Why would you not recommend continuing to study the effect of bioenergy on environment?

- Since a decision has already been made, it is a dead issue so no need to continue collecting data (Score 0)
- That a decision has already been made implies that there was sufficient information to make that decision. So, no more study is needed. (Score 0)

If B, then: Why would you recommend continuing to study the effect of bioenergy on environment?

- Collecting additional data would help address and clear criticisms from groups that disagree with my decision. (Score 1)
- Collecting additional data will likely lead to a common agreement. (Score 0)
- Collecting additional data will help people continue discussing and re-evaluating my decision. (Score 2)

SSR DIMENSION: SKEPTICISM

9. At the national climate change forum, a group of scientists employed by the forest service and another group of scientists employed by the environmental activists provided expert opinions on the bioenergy issue. Would you expect their opinions to be similar?

(A) Expert opinions offered by the scientists employed by the forest service and the environmental activists will likely be similar

(B) Expert opinions offered by of the scientists employed by the forest service and the environmental activists will likely NOT be similar

If A, why would the opinions of both groups of scientists likely be similar?

- Science is an objective process based on data, so the opinions of both groups of scientists should be similar. (Score 0)
- While the data from both groups of scientists may be different initially, they will likely come to agreement after they share data with each other. (Score 0)
- Scientists are typically unconcerned with subjective opinions and are more concerned with reaching a result based on actual findings. So, the opinions of both parties will be similar. (Score 0)

If B, why would the opinions of both groups not likely be similar?

- The details behind the bioenergy issue are multifaceted and difficult to understand, so the scientists will likely have different opinions on the issue. (Score 1)
- While the data from both groups of scientists may be different initially, they will likely come to agreement after they share data with each other. (Score 0)
- The forest service and the environmental activists will hire scientists who have opinions consistent with the groups' goals, so the different scientists will offer different opinions. (Score 2)

10. In response to the criticism about the questionable effects of bioenergy plant on environment and pollutions, the forest service has suggested using part of its profits to hire a team of scientists dedicated to collecting data on some locations and giving regular

reports to the local community. The environmental activists' groups decide to hire a different group of scientists to also conduct an investigation. Would you expect the findings of these two groups of scientists to be similar or different?

(A) I **would expect** the findings of the two groups of scientists to be the **same**.

(B) I **would expect** the findings of the two groups of scientists to be **different**.

If A, then: Why would you expect the findings of both groups of scientists to be the **same**?

- Findings would be the same if the science was done correctly since science is an objective process. (Score 0)
- The scientists may have different findings at first but would eventually come to agreement after talking it out. (Score 0)
- Both groups of scientists will be studying the same Bt corn variety, so should get similar results. (Score 0)

If B, then: Why would you expect the findings of the two groups of scientists to be **different**?

- The two groups of scientists will be collecting data to support different perspectives, so findings will likely be different. (Score 2)
- The forest service has the money to pay for better scientists, and so their data will likely be more trustworthy. (Score 0)
- Findings may be different because each group of scientists may use different methods. (Score 1)

11. An environmental scientist at a prestigious university publishes an article in a top-ranked journal confirming that bioenergy helps to reduce global warming. Do you think this will change the bioenergy plant debate?

(A) I would expect the new findings to change the bioenergy plant debate.

(B) I would NOT expect the new findings to change the bioenergy plant debate.

If A, then: Why would you **NOT expect** this to change the bioenergy plant debate?

- The study is unnecessary since these findings have already been confirmed by an article cited by environmental activists. (Score 0)
- The opposing parties are already set in their beliefs, and so are unlikely to consider additional data which may change their opinions. (Score 0)
- The environmentalist scientist publishing this article is an outsider not directly involved in the debate, and so the parties involved are unlikely to consider the findings. (Score 0)

If B, then: Why would you expect this to change the bioenergy plant debate?

- After considering these new findings, both parties are likely to agree that bioenergy does not help to reduce global warming and will take action to correct the situation. (Score 0)
- The parties opposing bioenergy plant will use these findings to strengthen their position and influence overall opinion on the debate. (Score 2)
- The parties opposing bioenergy plant will use these findings to strengthen their position and influence overall opinion on the debate. (Score 1)

Appendix B

GMOs Scenario

Bt Corn Growing in the US

Bt corn is designed to contain a Bacillus thuringiensis gene that generates a toxin that protects the crop against pests. In 1999, Dr. John Losey and his colleagues at Cornell University published a letter in Nature which showed that Bt corn pollen had harmful effects on monarch butterfly larvae. This insect feeds on milkweed plants on the caterpillar or larval stage. Since a certain area of milkweed is growing next to cornfields, Losey and colleagues suggested that Bt corn pollen could drift on milkweeds and damage the monarch larvae. The authors addressed the environmental safety of Bt Corn and called for more scientific investigation.

The Environment Protection Agency (EPA) and researchers from six universities investigated the possible effects of Bt corn pollen on monarch butterfly and related species in the following year. They concluded that the effect of Bt corn on the populations of monarch butterflies is not significant. They noted that there are different types of commercially available Bt corn, and these varieties differ in the amount of toxins that the plants express in their tissues (Sears et al., 2001). They also recognized that the variety Bt176, which Dr. Losey and colleagues used, was not commonly used by farmers. This variety has since been phased out (USDA, 2015).

Recently, groups interested in the environment and human health have raised concerns about growing Bt corn crops across the US. They argued that Bt corn parts, including leaves, cobs, and pollen, can migrate away from source areas – a phenomenon which is not considered when Bt corn is licensed. They also have concerned about the evolution of resistance in corn pests (Dively et al, 2016) that has the potential to put U.S. corn production in jeopardy and spur the need for increased insecticide use. Human health groups have also warned that new substances engineered into some Bt corn can become new potentially life-threatening allergens. However, Monsanto, a biotech company that produces and sells Bt corn seed, denies that environmental risks from Bt corn are their responsibility. They assert that the farmers, who want to fight corn pests in their crops, are responsible, not the technology they are using. The U.S. Department of Agriculture is considering creation of new regulations for growing of Bt corn crops in America.

Should Bt corn be grown in the US?

References:

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Multiple Choice Test (Adapted from Romine et al., 2017)

What is your major? ________________________________

I understand that my responses will remain anonymous after the instructor gives credit for the assignment and give consent for my responses to be used in research.

- Yes
- No

SSR DIMENSION: COMPLEXITY

1. Is the issue of GMO a complex issue?

(C) Yes
(D) No

If A, then: Select the response below that best explains why the GMO issue is complex.

- The GMO issue is complex because it deals with complicated dimensions of biology and economics. (Score 1 pt)
- The GMO issue is complex because it presents multiple tradeoffs related to the supply of food and the environment. (Score 2 pts)
- The GMO issue is complex because we do not know all the consequences (positive and/or negative) of the process. (Score 1 pt)

If B, then: Select the response below that best explains why the Bt corn issue is a fairly straightforward issue.

- The farmer wants to improve yields, and Bt corn is a pest resistant species. Therefore, Bt corn is a positive development for our society. (Score 0 pt)
- Bt corn contains the Bt toxin in its tissues. Therefore, Bt corn should not be grown in nature. (Score 0 pt)
- Bt corn may generate controversies, but science and technology can be used to overcome these potential problems. (Score 0 pt)

2. Can the controversy associated with the growing of Bt corn crops in America be resolved easily?

(A) NO
(B) YES

If A, then: Why is the Bt corn case difficult to resolve?

- Because it involves balancing environmental concerns, demands for foods, and the economy. (Score 2)
- Because topics like the environment, human health, and the economy are complicated topics. (Score 1)
- Because the description of the case offers limited information. If more details were available, the issue would be easier to resolve. (Score 1)

If B, then: Why is the Bt corn case easy to resolve?

- It is clear that Bt corn produces a toxin meant to kill pest insects, and it is also beneficial for the economy; therefore, Bt corn should continue to be grown in the US. (Score 0)
- It is clear that Bt corn will lead to environmental problems; therefore, Bt corn should be discontinued in the US. (Score 0)
- Once scientists are able to analyze the complete case, they will be able to create a solution that is fair for all interested parties. (Score 0)

SSR DIMENSION: PERSPECTIVE-TAKING

3. How likely is it that the environment and human health advocacy groups and biotech company representatives would endorse the same solution to the Bt corn case?

(C) It is **very likely** that the environment and human health advocacy groups and biotech company representatives would endorse the same solution.
(D) It is **NOT very likely** that the environment and human health advocacy groups and biotech company representatives would endorse the same solution.

If A, then: Why is it very likely that the environment and human health advocacy groups and biotech company representatives would endorse the same solution?

- The two groups will likely collaborate and reach a shared solution. (Score 0)
- If two groups work toward a solution, they will end up with the same basic plan. (Score 0)
- An independent panel of experts could be called in to develop a solution that meets the needs of all interested parties. (Score 0)

If B, then: Why is it not very likely that the environment and human healthcare groups and biotech company representatives would endorse the same solution?

- The environment and human health advocacy groups and biotech company representatives have different priorities. (Score 2)
- The environment and human health advocacy groups and biotech company representatives have access to different pieces of information. (Score 1)

- The environment and human health advocacy groups and biotech company representatives have not had enough time to reach consensus. (Score 1)

4. How likely is it that the US Farmers and Ranchers Association (USFRA) and biotech company representatives would endorse the same solution to the Bt corn case.

(C) It is **very likely** that US Farmers and Ranchers Association (USFRA) and biotech company representatives would endorse the same solution.

(D) It is **NOT very likely** that US Farmers and Ranchers Association (USFRA) and biotech company representatives would endorse the same solution.

If A, then: Why is it very likely that US Farmers and Ranchers Association (USFRA) and biotech company representatives would endorse the same solution?

- The two groups will likely collaborate and reach a shared solution. (Score 0)
- If two groups work toward a solution, they will end up with the same basic plan. (Score 0)
- An independent panel of experts could be called in to develop a solution that meets the needs of all interested parties. (Score 0)

If B, then: Why is it not very likely that US Farmers and Ranchers Association (USFRA) and biotech company representatives would endorse the same solution?

- The US Farmers and Ranchers Association (USFRA) and biotech company representatives have different priorities. (Score 2)
- The US Farmers and Ranchers Association (USFRA) and biotech company representatives have access to different pieces of information. (Score 1)
- The US Farmers and Ranchers Association (USFRA) and biotech company representatives have not had enough time to reach consensus. (Score 0)

SSR DIMENSION: INQUIRY

5. If you were asked to make a decision on whether to stop or continue growing Bt corn, do you feel as though you have enough information to make a decision?

(C) **I feel I have sufficient information** to make a decision about whether to stop or continue growing Bt corn.

(D) **I do NOT feel I have sufficient information** to make a decision about whether to stop or continue growing Bt corn.

If A, then: Why is there sufficient information to make a decision about whether to stop or continue growing Bt corn?

- The benefits of growing Bt corn outweigh the risks. Growing Bt corn improve yields and brings money into the economy, both of which are important for the US. (Score 0)

- The risks of Bt corn outweigh the potential benefits. Growing Bt corn brings health risks and reduces biodiversity, both of which will negatively affect the quality of life for the US people. (Score 0)
- Since research was done independently by the Environmental Protection Agency (EPA), the effects of growing Bt corn are clear. (Score 0)

If B, then: Why is there not sufficient information to make a decision about whether to stop or continue growing Bt corn?

- Everyone has different data. If the environment and human health advocacy groups, biotech company, and Environmental Protection Agency (EPA) agree on the proper data and collect it in a nonbiased way, then there will be sufficient information to make a decision. (Score 0)
- I am not sure about the economic and scientific details behind growing Bt corn, and thus, I should do more reading before I can make a decision. (Score 1)
- The long-term risks and benefits of Bt corn are unclear and need more study before a decision can be made. (Score 2)
- It is still unclear whether or not Bt corn is causing monarch butterfly decline and other health risks. This needs to be confirmed before a decision can be made. (Score 2)

STUDENT'S OPINION
6. If you were forced to make a decision whether to stop or continue Bt corn based on the information in the article, what decision would you make?
- Stop Bt corn growing
- Continue Bt corn growing

7. Do you think the US Farmers and Ranchers Association (USFRA), the environment and human health advocacy groups, biotech company, and Environmental Protection Agency (EPA) would agree with your decision?
(C) I feel all parties **would agree** with my decision.
(D) I feel one or more of the parties **would not agree** with my decision.

If A, then: Why would all parties agree with your decision?
- If all parties looked at the issue without bias, then it is clear that Bt corn is causing more harm than good. (Score 0)
- If all parties looked at the issue without bias, then it is clear that the benefits of Bt corn outweigh the potential harmful effects. (Score 0)

If B, then: Why would one or more parties likely not agree with your decision?

- Certain parties will disagree because they do not have proper understanding of the risks and benefits of Bt corn. (Score 0)
- It is unlikely that I could get all parties to agree with my decision because their agreement depends on whether or not they are benefitting from Bt corn. (Score 2)
- It is unlikely that all parties would agree at first due to their different perspectives. However, they would eventually come to a common agreement about the best course of action to take. (Score 1)

8. If the decision you made on whether to stop or continue Bt corn were put into action, would you recommend that additional funds and resources be used to continue studying the effect of Bt corn on monarch butterfly population?

(C) I **would NOT recommend** continuing to study the effect of Bt corn on monarch butterfly population.

(D) I **would recommend continuing** to study the effect of Bt corn on monarch butterfly population.

If A, then: Why would you not recommend continuing to study the effect of Bt corn on monarch butterfly population?

- Since a decision has already been made, it is a dead issue so no need to continue collecting data. (Score 0)
- That a decision has already been made implies that there was sufficient information to make that decision. So, no more study is needed. (Score 0)

If B, then: Why would you recommend continuing to study the effect of Bt corn on monarch butterfly population?

- Collecting additional data would help address and clear criticisms from groups that disagree with my decision. (Score 1)
- Collecting additional data will likely lead to a common agreement. (Score 0)
- Collecting additional data will help people continue discussing and re-evaluating my decision. (Score 2)

SSR DIMENSION: SKEPTICISM

9. At the national agriculture forum, a group of scientists employed by the biotech company and another group of scientists employed by the EPA provided expert opinions on the Bt corn issue. Would you expect their opinions to be similar?

(C) Expert opinions offered by the scientists employed by the EPA and the biotech company **will likely** be similar

(D) Expert opinions offered by of the scientists employed by the EPA and the biotech company **will likely NOT** be similar

If A, why would the opinions of both groups of scientists likely be similar?

- Science is an objective process based on data, so the opinions of both groups of scientists should be similar. (Score 0)
- While the data from both groups of scientists may be different initially, they will likely come to agreement after they share data with each other. (Score 0)
- Scientists are typically unconcerned with subjective opinions and are more concerned with reaching a result based on actual findings. So, the opinions of both parties will be similar. (Score 0)

If B, why would the opinions of both groups not likely be similar?

- The details behind the Bt corn issue are multifaceted and difficult to understand, so the scientists will likely have different opinions on the issue. (Score 1)
- While the data from both groups of scientists may be different initially, they will likely come to agreement after they share data with each other. (Score 0)
- The biotech company and EPA will hire scientists who have opinions consistent with the groups' goals, so the different scientists will offer different opinions. (Score 2)

10. In response to the criticism about the questionable effects of Bt corn growing on environment and human health, the biotech company has suggested using part of its profits to hire a team of scientists dedicated to collecting data on Bt corn crops in the area and giving regular reports to the local community. The environmental and human health groups decide to hire a different group of scientists to also conduct investigation. Would you expect the findings of these two groups of scientists be similar or different?

(C) I **would expect** the findings of the two groups of scientists to be the **same**.

(D) I **would expect** the findings of the two groups of scientists to be **different**.

If A, then: Why would you expect the findings of both groups of scientists to be the **same**?

- Findings would be the same if the science was done correctly since science is an objective process. (Score 0)
- The scientists may have different findings at first but would eventually come to agreement after talking it out. (Score 0)
- Both groups of scientists will be studying the same Bt corn variety, so should get similar results. (Score 0)

If B, then: Why would you expect the findings of the two groups of scientists to be **different**?

- The two groups of scientists will be collecting data to support different perspectives, so findings will likely be different. (Score 2)
- The biotech company has the money to pay for better scientists, and so their data will likely be more trustworthy. (Score 0)
- Findings may be different because each group of scientists may use different methods. (Score 1)

11. A biologist at a prestigious university publishes an article in a top-ranked journal confirming that Bt corn was not a threat to the monarch butterfly. Do you think this will change the GMO debate?

(C) I **would NOT expect** the new findings to change the GMO debate.

(D) I **would expect** the new findings to change the GMO debate.

If A, then: Why would you **NOT expect** this to change the GMO debate?

- The study is unnecessary since these findings have already been confirmed by the EPA. (Score 0)
- The opposing parties are already set in their beliefs, and so are unlikely to consider additional data which may change their opinions. (Score 0)
- The biologist publishing this article are outsiders not directly involved in the debate, and so the parties involved are unlikely to consider the findings. (Score 0)

If B, then: Why would you **expect** this to change the GMO debate?

- After considering these new findings, both parties are likely to agree that Bt corn crop is the cause of monarch butterflies decline and will take action to correct the situation. (Score 0)
- The parties opposing Bt corn will use these findings to strengthen their position and influence overall opinion on the debate. (Score 2)
- The opposing parties will likely interpret the report differently which may drive the debate further from reaching a solution. (Score 1)

How interested are you in ...?

Please check a number to the right of each description, to represent your interest in the corresponding topic.

1 = Very Uninterested
2 = Somewhat Uninterested
3 = Uncertain
4 = Somewhat Interested
5 = Very Interested

	1	2	3	4	5
Understanding the scientific knowledge behind the controversies regarding GMO					
Understanding the societal perspectives behind the controversies regarding GMO					
Negotiating potentially solutions for the controversies regarding GMO					
Evaluating all stakeholders' perspectives regarding GMO					
Pursuing an in-depth project related to GMO					

Appendix C

Vaccinations Scenario:

Heroin Vaccine

In 2016, sixty-four thousand Americans died of overdose medications. At least two thirds of the medications were related to the opioids class, including oxycodone, hydrocodone, codeine, morphine, and fentanyl, which contain heroin and prescription pain relievers. The number of users of heroin in the US tripled to 1 million between 2003 and 2014, and the approximate cost of heroin misuse is about 50 billion US dollars a year. These figures show that the abuse of opioids like heroin is a rising problem in the United States.

In seconds from entering the bloodstream, heroin has been characterized as "a warm blanket of the brain" - it strikes receptor molecules in the neurons causing an outbreak of euphoria, followed by a long feeling of tranquility, which is likely to contribute towards its addictive existence. California researchers have recently confirmed the development of a vaccine that can block the effects of heroin drug use on mice and monkeys, and suggest human clinical tests are on the horizon. If a single dose of the vaccine could nullify for several weeks the altering emotional effects of heroin at a time, it could break the opioid cycle.

The vaccine works by encouraging the B-cells to make antibodies that specifically bind with heroin in the blood before the drug crosses the blood-brain barrier, thus preventing the euphoric effects of heroin. In this case, the vaccine is not doing what it normally does, which is to boost immunity to an antigen on a pathogen, like a bacteria or virus. Instead, the antibody binding would inhibit heroin from triggering nervous system receptors and block its euphoric effects. Interestingly, the antibodies induced by the vaccine only bind to heroin molecules and do not cross-react with therapies for opioid misuse (such as methadone, buprenorphine, naltrexone), non-narcotic pain relievers (aspirin, ibuprofen, acetaminophen), and other common treatments for overdose.

As these studies were published, **many pharmaceutical companies** have expressed interest in the vaccine. They expect a vaccine for heroin will protect against overdose of heroin. Scientists believe these studies will bring forth vaccines that produce higher levels of antibodies so that in combination with rehabilitation, drug addiction will become a treatable problem. There is strong interest in supporting further research on this vaccine as well as interest in conducting human trials.

However, some **specialists in drug addiction** have expressed concerns regarding the treatment. They said the vaccine may only work in the short term for preventing a 'high' and require repeated doses. A heroin vaccine may play a role in fighting the drug use epidemic, but it is no cure. Their reasoning is focused on the specificity of the immune response, someone who has been vaccinated against heroin would almost certainly still respond to morphine, and most definitely would also respond to compounds like fentanyl or oxycodone. That means the addict might just switch to one of the other opioids that the vaccine does not affect. There is also concern about the length of time during which immune protection would be active in humans (e.g. how many booster shots would be needed), and effectiveness could vary from person to person (e.g. between young children and adults). Therefore, they do not want to conduct human trials unless we had clear answers regarding safety and effectiveness.

Individuals from the **Substance Abuse and Mental Health Services Administration (SAMHSA)** argue that drug addiction is not only a simple biochemical problem, but a behavioral problem and a choice. Some people say that breaking the habits of users is more than a matter of simply interfering with the effectiveness of the heroin. There is also concern that larger doses of the vaccine may create significant stress on the immune system and trigger a negative response. They predict an addict could take a higher dose of heroin in an attempt to overwhelm the vaccine response. Finally, they share the concern that the vaccine would not work against opiates that are structurally distinct from heroin, which may motivate a user to find new ways to go on abusing drugs.

The government is considering this vaccine proposal in human-trials and will decide whether to fund it or not.

Personal Interest Survey:

How interested are you in ...?

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	1	2	3	4	5
Understanding the scientific knowledge behind the controversies regarding vaccinations					
Understanding the societal perspectives behind the controversies regarding vaccinations					
Negotiating potentially solutions for the controversies regarding vaccinations					
Evaluating all stakeholders’ perspectives regarding vaccinations					
Pursuing an in-depth project related to vaccinations					

VITA

Hai Thanh Nguyen was born on August 27th, 1983 in Da Nang, Vietnam, where he completed his elementary and secondary education. He earned a Bachelor of Science in Biotechnology and a Master of Science in Plant Physiology from the University of Science in Ho Chi Minh City, Vietnam. He worked as a college instructor a few years before he decided to pursue his graduate studies abroad. He attended the University of Missouri as part of the Vietnam Education Foundation fellowship program in 2011. After completing the Master of Science in Plant Science in the University of Missouri-Columbia, Hai decided to pursue his doctorate in Science Education because he was inspired by real stories in science education at the MU and he was keen to engage in the reform of his country's education. Hai plans to take postdoctoral training before going back to Vietnam to obtain a faculty position at the university. His future emphasis teaching and research will remain on supporting teachers and students in science education.