THE EFFECTS OF EPISTEMIC BELIEFS ON STUDENTS' EMOTIONS AND ATTITUDES TOWARDS GENETICALLY MODIFIED FOODS

by

David Andrew Lee

Liberty University

A Dissertation Presented in Partial Fulfillment

Of the Requirements for the Degree

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APPROVED BY:

Jillian L. Wendt, Ed.D., Committee Chair

Michelle Barthlow, Ed.D., Committee Member & Methodologist

ABSTRACT

Much research has explored socio-scientific issues (SSIs) in science instruction, including the connections between conceptions and attitude. Studies have also shown that epistemic beliefs affect epistemic emotions, which are a key component of students' reaction to complex scientific topics. Correcting misconceptions can also result in emotional and attitude change, particularly surrounding the topic of genetically modified foods (GMFs). However, the impact of epistemic beliefs on emotions and attitude towards GMFs has largely gone unexplored. The purpose of this study is to examine the effects of epistemic beliefs on epistemic emotions and attitudes towards GMFs. This quantitative correlational study sampled 78 students from a large Christian university in Virginia. Participants were assessed for epistemic belief, then read refutation and persuasive texts about GMFs prior to completing questionnaires about epistemic emotions and attitudes towards GMFs. These variables were measured using the following instruments: the Epistemic Belief Inventory (EBI), the Epistemically-Related Emotion Scales (EES), and the Attitudes about GMFs survey. The results did not indicate a predictive relationship between epistemic beliefs and emotions or attitudes towards GMFs. However, a significant predictive relationship between negative epistemic emotions and negative attitudes towards GMFs was found. As a result, the null hypothesis was rejected, and the regression analysis yielded a significant effect size. The contribution of these findings to the scholarly literature, as well as their practical implications, is discussed.

Keywords: attitudes, socio-scientific issue (SSI), genetically modified foods (GMFs), epistemic beliefs, epistemic emotions

Dedication

This doctoral dissertation is dedicated to my family. Mandy, your ceaseless love made this possible, while your support and patience helped keep me sane. Edison, you helped lift my spirits on the difficult days. I love you both so much and cannot thank you enough.

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First and foremost, I am indebted to my Lord and Savior, Jesus Christ. Anything good that I have done is but filthy rags next to His righteousness, and is only possible due to His grace working in my life. He has regularly sustained me with peace that passes understanding, and by blessing me with the support of friends, family, and the local church.

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List of Abbreviations

American Association for the Advancement of Science (AAAS)

Epistemic Belief Inventory (EBI)

Epistemically-Related Emotion Scales (EES)

Genetically modified (GM)

Genetically modified food (GMF)

Genetically modified organism (GMO)

National Academies of Science, Engineering, and Medicine (NASEM)

Socio-scientific issue (SSI)

CHAPTER ONE: INTRODUCTION

Overview

The interaction of epistemic beliefs and emotions in science education is a growing field of research. Such research is typically carried out using scientific topics with strong societal impact, known as socio-scientific issues (SSIs). However, while a growing body of research has explored epistemic beliefs and emotions, as well as attitudes towards SSIs, few have addressed the interaction of all three factors. The purpose of this study is to examine the effect of epistemic beliefs on epistemic emotions and attitudes towards genetically modified foods (GMFs). This chapter will summarize the historical and theoretical background for this topic and establish the problem that warrants this research. Next, the purpose of the study and its significance will be discussed. The chapter will conclude by outlining the research questions and defining key terms.

Background

The use of SSIs as interventions in science education has been studied extensively, particularly in college classrooms. SSIs allow students to interact with pressing issues and apply scientific concepts to them. Common examples include evolution, climate change, and GMFs (Borgerding et al., 2017; Dinsmore et al., 2017; Heddy et al., 2017; Muis et al., 2015; Potter et al., 2017). Much of this research has sought to address the conceptual factors behind student understanding. For example, Coley and Tanner (2015) found that agreement with scientific misconceptions about evolution were fairly persistent, even among biology majors. Other studies have sought to address attitudes towards SSIs by addressing such misconceptions. To that end, refutation texts have been used to correct common misconceptions about SSIs and have correlated to more positive attitudes and more effective learning strategies (Heddy et al., 2017; Muis, Sinatra et al., 2018). When used in conjunction with persuasive texts, such strategies have shown particular promise in fostering conceptual and attitude change about GMFs (Muis et al., 2020; Thacker et al., 2020).

The correlation between conceptual understanding and attitudes about GMFs has also been observed in survey data. Genetically modified (GM) crops have been evaluated as safe by the American Association for the Advancement of Science (AAAS) as well as the National Academies of Science, Engineering, and Medicine (NASEM) (AAAS, 2013; NASEM, 2016). When surveyed, 88% of AAAS members responded that GM crops are safe to eat. However, in the same survey, only 37% of American adults responded thusly, demonstrating a 51% gap between public and scientist attitudes (Pew Research Center, 2015). In a series of surveys, skepticism of GMFs increased sharply among American adults in just two years. In 2016, 39% responded that GMFs were worse for health than other foods, which rose to 49% by 2018 and to 51% in 2020 (Funk, 2020; Kennedy et al., 2018; Pew Research Center, 2016). However, this disapproval grew primarily among those with lower levels of scientific literacy, while those with higher levels did not change substantially (Kennedy et al., 2018). An international study also showed a strong correlation between GMF skepticism and a lack of literacy regarding GM technology (McPhetres et al., 2019). These attitudes are not only indicative of the state of scientific literacy but indicate opposition to technology with significant benefits for human health and the environment. GM crops have the capacity to reduce insecticide use, produce more food on less land, and combat vitamin A deficiency in the developing world (Clark & Tilman, 2017; Dively et al., 2018; Regis, 2019).

However, attitudes towards SSIs are not simply conceptual in nature, but also rely on beliefs about the nature of knowledge known as epistemic beliefs. In their literature review of inquiry methods, Fang et al. (2019) noted a trend of epistemic beliefs strongly influencing on evidence-based reasoning. The theory of conceptual change, described by Posner et al. (1982), provides the framework for this understanding. This theory was inspired in part by Thomas Kuhn's (1970) seminal book, *The Structure of Scientific Revolutions*, which describes the process of paradigm shifts in the history of scientific research, such as the transition from Newtonian to Einsteinian physics. Posner et al. (1982) note similarities between these transitions and the reassessment of conceptual understanding in individuals. When a student encounters new information, they may either assimilate it into their current conception or reorder their conception in order to accommodate the new information. This conceptual change is driven by governing concepts, including epistemic beliefs and prior knowledge. Epistemic beliefs can be described in a variety of ways, including Perry developmental levels of dualist, multiplist, relativist, and dialectical. In this paradigm, students generally begin with more absolutist beliefs (dualists). But as they develop, they become more open to other perspectives and subjective explanations (multiplists and relativists), eventually becoming more comfortable with uncertainty and relativism (dialectical) (Borgerding et al., 2017; Rosman & Mayer, 2018).

Another way to categorize epistemic beliefs is through informal patterns of reasoning known as cognitive construals. These cognitive construals can serve as helpful linguistic shorthand, but often reinforce biological misconceptions (Richard et al., 2017). For example, essentialism is the belief that an underlying aspect of an item defines its essence and cannot be modified without redefining that item. Essentialist reasoning has been correlated with a greater degree of biological misconceptions (Coley & Tanner, 2015; Richard et al., 2017; Stern et al., 2018). Such misconceptions are particularly apparent with the topic of GMFs (Potter et al., 2017). Epistemic beliefs can also be described in a more detailed and multidimensional way. These dimensions include beliefs about the simplicity of knowledge, the certainty of knowledge, the source of knowledge, the innate ability to learn, and the speed of learning (Bullock, 2018). Beliefs related to these types of factors range from more constructivist to less constructivist, and have been used in research in science education (Muis, Chevrier et al., 2018). For example, belief that knowledge is certain and that learning relies on the learner's innate ability was correlated with poor ability to construct arguments concerning SSIs (Ozturk & Yilmaz-Tuzun, 2017).

In addition to conceptual and belief factors, students' attitudes towards SSIs are also affected by emotional factors. Emotions and attitudes are dictated by a number of factors, including individual values, which play an important role in SSI decision making (Fang et al., 2019). In his control-value theory of emotion, Pekrun (2006) described the factors affecting activity-related and outcome emotions. Pekrun posited that emotional response was dictated by the perceived influence students have on their outcome (control) and the relevance the topic has on them personally (value). Particularly relevant in science education, epistemic emotions are those that result from evaluation of information and can dictate future learning (Muis, Chevrier et al., 2018). Common epistemic emotions include curiosity, surprise, enjoyment, anxiety, confusion, frustration, and boredom (Pekrun et al., 2017). Such emotions can have an activating or deactivating effect, and have been shown to impact learning strategies and outcomes. Muis et al. (2015) found that positive epistemic emotions predict deeper processing and critical thinking among college students engaging with conflicting information about climate change. In a similar study, Chevrier et al. (2019) demonstrated how surprise drives more critical thinking and how curiosity leads to greater self-reflection.

Historically, research into SSIs has largely focused on "cold" intellectual factors, but more studies are recognizing the relevance of the "hot" factors of emotions to such topics

(Rosman & Mayer, 2018). The resulting "warming trend" has driven more research interest into the interaction of beliefs and emotions (Leonard et al., 2014; Sinatra & Seyranian, 2016). When students encounter conflicting information, their epistemic beliefs inform their emotional response. Muis et al., (2015) found that students with more constructivist epistemic beliefs showed lower levels of negative emotions, such as confusion, anxiety, and boredom. They also showed higher levels of positive emotions, such as enjoyment and curiosity. Similarly, Chevrier et al. (2019) demonstrated that more constructivist students showed greater curiosity and less boredom.

Emotions also inform the formation of attitudes, which are general appraisals or judgments of a particular subject and may be positive or negative (Heddy et al., 2017). In conjunction with the aforementioned "warming trend", Sinatra and Seyranian (2016) proposed a framework of attitude/conceptual change. In this model, the accuracy of a participant's conceptions is compared with their attitude for or against the topic at hand. Correcting misconceptions can result in conceptual change from inaccurate to accurate understanding of the topic. However, Sinatra and Seyranian (2016) also proposed that conceptual change could result in a change in attitude from opposition to support. This was demonstrated experimentally by Heddy et al. (2017), who studied students' attitudes towards GMFs. The results indicated that correcting misconceptions using a refutation text resulted in more positive attitudes towards GMFs. Thacker et al. (2020) further established the role of epistemic emotions in mediating change in attitudes towards GMFs. Epistemic beliefs and judgments have also been shown to impact epistemic emotions related to GMFs (Muis et al., 2020, 2021).

In summary, attitudes towards SSIs are subject to influence from conceptual understanding, epistemic beliefs, and emotions. Refutation texts are a common tool used to correct misconceptions, which can lead to attitude change (Heddy et al., 2017; Muis, Sinatra et al., 2018). Epistemic beliefs impact student interaction with and application of scientific concepts, and can lead to more accurate conceptions (Posner et al., 1982; Potter et al., 2017). Moreover, epistemic beliefs affect epistemic emotions, which drive students' reaction to conflicting information and learning strategies (Chevrier et al., 2019; Muis et al., 2015). Finally, conceptual change has also been shown to result in attitude change, which is mediated by emotional change (Heddy et al., 2017; Sinatra & Seyranian, 2016; Thacker et al., 2020).

Problem Statement

Several studies have addressed the topics of epistemic belief, epistemic emotion, and attitudes towards SSIs among undergraduate students (Chevrier et al., 2019; Heddy et al., 2017; Muis et al., 2015; Rosman & Mayer, 2018). However, the interaction between each of these factors has not been studied. The impact of epistemic beliefs on epistemic emotions has been documented among college students, but not regarding SSIs (Rosman & Mayer, 2018). Studies centered on SSIs have largely focused on climate change and have gone on to discuss the consequences of such emotions on learning strategies and outcomes (Chevrier et al., 2019; Muis et al., 2015). Similarly, the impact of epistemic beliefs on attitudes has been addressed, but only towards science in general among education undergraduate students (Bullock, 2018).

This field of inquiry is ripe for further study (Sinatra & Seyranian, 2016). The relationship between emotional change and attitude change has been theorized (Petty & Briñol, 2015) and modeled in the attitude/conceptual change framework (Sinatra & Seyranian, 2016). Moreover, this interaction has been studied concerning college students' attitudes toward GMFs (Heddy et al., 2017; Muis et al., 2020; Thacker et al., 2020). However, only one study has explored the role of prior epistemic beliefs in relation to epistemic emotions surrounding GMFs, and this study did not address attitude change (Muis et al., 2021). There is a gap in the research literature concerning the effects of epistemic beliefs and emotions on attitudes towards GMFs.

In summary, much research has explored the effects of epistemic beliefs on emotions. Other studies have addressed conceptual and attitude change towards SSIs. The problem is that the role of epistemic beliefs on emotions and attitude towards GMFs has not been thoroughly explored. Enhanced understanding of this relationship would allow more targeted science education regarding the topic of GMFs, as well as other controversial SSIs.

Purpose Statement

The purpose of this study is to examine the effects of epistemic beliefs on epistemic emotions and attitudes towards GMFs. This was accomplished using a quantitative, predictive correlational design to assess the interaction between these three variables. Epistemic beliefs are beliefs about the nature of knowledge and its acquisition (Schraw et al., 2002). Epistemic emotions are emotions related to the generation of knowledge and learning (Pekrun et al., 2017). In contrast, an attitude is a general appraisal or judgment of a subject and may be positive or negative (Heddy et al., 2017).

The study participants included 78 undergraduate students of various majors taking introductory science courses. Participants were drawn from a large, private Christian university in central Virginia. Participants completed the aforementioned measures in an online survey format, and also read a refutation text designed to correct common misconceptions about GMFs, as well as a persuasive text highlighting their advantages (Thacker et al., 2020).

This study assessed epistemic beliefs and epistemic emotions. Epistemic beliefs were measured using the Epistemic Belief Inventory (EBI) and served as one of the predictor variables (Schommer, 1990; Schraw et al., 2002). Epistemic emotions were measured using the

Epistemically-Related Emotion Scales (EES), serving as both predictor and criterion variables in different research questions (Pekrun et al., 2017). Attitudes towards GMFs, were measured using Heddy et al.'s (2017) Attitudes about GMFs survey and served as a criterion variable.

Significance of the Study

An examination of the relationship between epistemic beliefs and emotions on attitudes towards GMFs adds to the body of knowledge concerning the role of these factors in SSI instruction. This study further clarifies the consequences of epistemic emotions studied by Muis et al. (2015) and Chevrier et al., (2019). Moreover, it complements the findings of Heddy et al., (2017) by addressing the impact of epistemic beliefs on attitudes towards GMFs. These findings yielded implications for future study of emotional change and attitude change, as well as the use of refutation texts to promote such change (Heddy et al., 2017; Muis, Sinatra et al., 2018).

This study also had practical significance for instruction, building on other studies that show positive epistemic emotions resulting in more effective learning strategies (Chevrier et al., 2019; Muis et al., 2015). The results of this study can provide a basis for development of future instructional practices that factor in epistemic beliefs and emotions. Furthermore, it expands on the research of Potter et al. (2017), who addressed the connection between epistemic beliefs and GMF misconceptions. The overarching goal is to further clarify student conceptions and attitudes towards GMFs in order to help create more scientifically literate citizens.

Research Questions

RQ1: Do *epistemic beliefs* of undergraduate students predict *epistemic emotions* following refutation of common misconceptions about GMFs?

RQ2: Do *epistemic beliefs* of undergraduate students predict *attitudes towards GMFs* following refutation of common misconceptions?

RQ3: Do *epistemic emotions* of undergraduate students predict *attitudes towards GMFs* following refutation of common misconceptions?

Definitions

1. *Attitude* – An attitude is a general appraisal or judgment of a subject and may be positive or negative (Heddy et al., 2017).
2. *Epistemic beliefs* – Epistemic beliefs are beliefs about the nature of knowledge and its acquisition (Schraw et al., 2002).
3. *Epistemic emotions* – Epistemic emotions are emotions related to the generation of knowledge and learning (Pekrun et al., 2017).
4. *Genetically modified food (GMF)* – Genetically modified foods are those produced using organisms whose genetic material has been altered in a way that does not occur naturally (World Health Organization, 2014).
5. *Socio-scientific issues (SSIs)* – Socio-scientific issues are scientific topics or dilemmas of particular social interest (Sadler, 2004).
6. *Cognitive construals* – Cognitive construals are a type of informal reasoning based on intuitive patterns of thought (Coley & Tanner, 2015)

CHAPTER TWO: LITERATURE REVIEW

Overview

The purpose of this study is to examine the effects of epistemic beliefs on epistemic emotions and attitudes towards GMFs. The factors that determine how college students approach SSIs, such as GMFs, have garnered much attention in the academic literature. This literature has been systematically reviewed with an emphasis on the role of beliefs and emotions in dictating students' attitudes and views regarding such issues. First, the theory of conceptual change will be discussed along with the control-value theory of emotion, both of which build the theoretical framework. The relevant literature will then be synthesized regarding primary types of informal reasoning, such as epistemic beliefs and construal-based reasoning. Next, the role of emotions in science learning, particularly while encountering conflicting information, will be addressed. Finally, the current state of understanding regarding the interplay of beliefs and emotions will be explored, including view complexity and the models of conceptual and attitude change. While much research has explored these factors, few have sought to assess the impact of epistemic beliefs and emotions on attitudes towards GMFs. This present study seeks to address this gap in the literature.

Theoretical Framework

Students' attitudes towards SSIs are dependent on a variety of factors. This framework will serve to outline the foundational theories of conceptual change and evaluation, particularly related to scientific controversies. Posner et al.'s (1982) theory of conceptual change described cognitive accommodation as a factor of properties of the students' conceptual ecology. On the other hand, Pekrun (2006) addressed the emotional factor with his control-value theory of emotion, positing that learning drives emotional responses through a student's appraisals of control and value.

Theory of Conceptual Change

Studying SSIs often requires students to reevaluate their preconceptions and, at times, revise their beliefs. Posner et al. (1982) provided a theoretical framework for such conceptual change and the conditions required to foster it within students. This theory was inspired by Thomas Kuhn's (1970) seminal book, *The Structure of Scientific Revolutions*, which describes the process of paradigm shifts in the history of scientific research, such as the move from Newtonian to Einsteinian physics. Posner et al. note similarities between these transitions and the replacement of concepts in individuals. When a student encounters new information, they may either assimilate it into their current conception or reorder their conception in order to accommodate the new information. According to Posner et al. (1982), accommodation requires careful assessment of both current and new concepts. The student must be dissatisfied with their current conception's ability to make sense of the information and must recognize the intelligibility and plausibility of a new concept. Finally, this replacement concept should also potentially allow for productive research ventures. These governing concepts are referred to as the conceptual ecology, which is also characterized by epistemic beliefs, metaphysical beliefs, other knowledge, and other cognitive conflicts called anomalies (Posner et al., 1982). This conceptual ecology must be addressed in order for a student to update their conceptions and attitudes about SSIs in light of new evidence. One key factor in such a reconsideration is the evaluation of the plausibility of the new concept.

Building on Posner et al.'s (1982) classical conceptual change model, Lombardi et al. (2016) proposed the Plausibility Judgments in Conceptual Change (PJCC) model. According to this model, humans innately pre-process new claims for validity based on background knowledge, the complexity of new explanations, and perceptions of the certainty and credibility of the source. Because such judgments are made implicitly, prior conceptions are prone to persist because of their perceived plausibility. However, according to the PJCC model, previous conceptions can be reappraised through critical evaluation of alternative explanations (Lombardi, Nussbaum, et al., 2016).

Control-Value Theory of Emotion

Students' attitudes about SSIs are influenced by intellectual and emotional factors. Posner et al.'s (1982) theory provided a framework for understanding conceptual change; but it only addressed the formal intellectual basis informing such change. Emotions also play a significant role in students' interactions with new knowledge, particularly when it challenges their preconceptions. Pekrun (2006) posited that learning has positive and negative effects on emotions, which were categorized as activity-related and outcome emotions. His control-value theory of emotion argued that this influence is mediated by appraisals of students' perceived control over the learning outcome as well as the personal value they placed on the subject. Furthermore, individual personality antecedents have the capacity to influence the process, which is subject to interplay and feedback mechanisms (Pekrun, 2006).

Pekrun's work formed the foundation for other theoretical models that sought to explain the interplay between epistemic beliefs and emotions. In her model of epistemic beliefs and self-regulated learning, Muis (2007) posited that epistemic beliefs serve as epistemological standards, which inform student motivation to learning activities. However, this model did not incorporate the role of epistemic emotions. On the other hand, Bendixen and Rule (2004) argued that cognitive incongruity, or disequilibrium, drives changes in epistemic beliefs by inducing epistemic emotions. In their cognitive incongruity model of epistemic beliefs and emotions, Muis et al. (2015) brought these factors together, positing that epistemic beliefs impact epistemic emotions, which in turn affect learning strategies and outcomes. According to this integrative model, when a student encounters complex material, such as SSIs, this can trigger cognitive incongruity with their prior epistemic beliefs. This incongruity informs the resulting epistemic emotional response, which influences the learning strategies used to process the conflicting material and the resulting outcomes (Muis et al., 2015). These models have been used to inform empirical research and can be further applied to educational practice, particularly related to SSIs.

Related Literature

SSIs are socially and scientifically embedded topics and are commonly used to help students apply scientific concepts to real-world situations. Examples of SSIs include climate change, acceptance of evolution, nuclear power, and genetically modified organisms (GMOs), particularly in agriculture (Borgerding et al., 2017; Dinsmore et al., 2017; Heddy et al., 2017; Muis et al., 2015; Ozturk & Yilmaz-Tuzun, 2017; Potter et al., 2017). In a review of the SSI literature, Sadler (2004) argued that they can be important interventions for the development of informal reasoning. While not a panacea, SSIs also provide opportunities for students to develop epistemic cognition and argumentation skills (Sadler, 2004).

However, despite extensive research into the use of SSIs as interventions, the factors affecting students' attitudes towards them have not been as thoroughly described. In their literature review, Fang et al. (2019) established a framework for conceptualizing student decision making about SSIs. They found that most studies focused on articulating a decision-making space and addressed themes of evidence-based and informal reasoning. On the other hand, far fewer studies have addressed the establishment of a decision-making strategy or the reflection on that process (Fang et al., 2019).

SSIs are of interest specifically because of their embeddedness within society, which means that they are not simply conceptual topics. Rather, the study of SSIs often requires appraisals of epistemic beliefs (Chevrier et al., 2019). The role of emotions must also be considered, including the way people assess risk (Loewenstein et al., 2001) and new information which conflicts with their prior understanding (Bendixen & Rule, 2004).

Genetically Modified Foods (GMFs)

While several SSIs have been studied, the topic of GMFs raises particular interest due to the strong public reaction to it, and the abundance of controversy it incites. The World Health Organization (2014) defines genetically modified organisms (GMOs) as plants, animals, or microorganisms "in which the genetic material (DNA) has been altered in a way that does not occur naturally by mating and/or natural recombination" (World Health Organization, 2014, para. 1). While there is some innate ambiguity with the term, a "GMO" typically refers to an organism that is transgenic, meaning it contains genes from another species (Dively et al., 2018). Because the term "GMO" can apply to biotechnological applications in a variety of disciplines "GMF" is here used to focus on the agricultural context.

Genetically Modified (GM) crops provide a number of agricultural benefits, including resistance to pests, herbicides, disease and drought, as well as extreme cold and salinity (Whitman, 2000). These innovations allow greater yield and less crop loss for farmers around the world. One prominent example is Bt corn, which has been modified to include a gene from the bacterium *Bacillis thuringensis*, from which it gets its name. This gene allows the corn to produce a chemical that is toxic to pests such as corn borers, but not to humans or other animals

(Dively et al., 2018). Dively et al. (2018) analyzed 40 years of data and found that the use of Bt corn regularly reduced harmful pests and crop damage, as well as a 41% reduction in insecticide use. Through these types of benefits, GM crops also allow greater yield, meaning more food can be grown on less land. In a meta-analysis of 90 crops over several hundred sites, Clark and Tilman (2017) found that land use was higher for crops grown using conventional agricultural techniques, including genetic engineering, when compared to crops grown organically.

While these types of studies show obvious agricultural benefit of GM crops, the question of GMF safety is a separate matter. Public concern regarding safety of GMFs is focused on the perception that they cause allergic reactions or illness (Rose et al., 2020). However, the scientific evidence for this concern has not been borne out. In 2016, the National Academies of Science, Engineering, and Medicine (NASEM) reviewed the scientific literature for safety of GM crops and found no compelling evidence that they are correlated with adverse health risks. In fact, the authors cited the benefits of reducing insecticide poisoning, as well as the development of GM crops with improved nutrition (NASEM, 2016). Additionally, the use of Bt corn has been found to reduce fungal toxins in corn by 90% (Dively et al., 2018). An excellent example of improved nutrition is the development of "Golden Rice", which includes a gene from daffodils that allows the rice to produce beta-carotene, a vital precursor in vitamin A formation. This crop was modified to treat vitamin A deficiency, which results in over 500,000 cases of blindness per year in the developing world (Regis, 2019).

Given the agricultural benefits and safety advantages of GM crops, it is unsurprising that they are largely considered safe by the scientific community. For example, the board of directors of the American Association for the Advancement of Science (AAAS) released in a statement that the evidence for the safety of GM crops was clear (AAAS, 2013). In a 2015 survey of

AAAS members by the Pew Research Center, 88% of the scientists surveyed responded that it was safe to eat GM foods (Pew Research Center, 2015).

However, the same survey showed the disconnect between scientists and the general public on this issue. When asked whether GM foods were safe to eat, only 37% of United States adults responded thusly. This represents the largest gap (51%) between public and scientists' perceptions of any of the SSIs surveyed, including climate change, vaccines, and evolution (Pew Research Center, 2015). In a 2016 survey, 39% of American adults viewed GMFs as worse for human health than other foods (Pew Research Center, 2016). This minority became more sizeable, with 49% of adults responding thusly to a 2018 survey (Kennedy et al., 2018), representing a ten-point uptick in just two years. Two years after that, this proportion reached a majority of 51% (Funk, 2020). This public distrust is not limited to the United States. A study of public perceptions of GMFs across 20 countries found that 48% of those surveyed viewed them as worse for human health. Only 13% of respondents said they were safe to eat, with sizeable percentages in each country saying they did not know enough to respond to answer (Kennedy & Thigpen, 2020).

While public opposition is not uncommon surrounding controversial scientific topics, this trend is particularly interesting because of the disparity between the views of scientists and the public. This public perception has resulted in the advent of mandatory labeling of GMFs in the United States (Prentice, 2018), despite the opposition to this effort by both the AAAS (2013) and NASEM (2016). Moreover, the opposition to GMFs in western developed nations stalled the adoption of "Golden Rice" for over 20 years, despite its capacity to improve the health of millions in the developing world (Regis, 2019).

The reasons for this disconnect between scientific and public attitudes towards GMFs are likely multifaceted. One possibility is a series of common misconceptions. Many are under the mistaken impression that GMFs involve cloning or hormone injection, which is not the case (Broughton et al., 2012). Another misconception is that GMFs are unnatural, making them dangerous for human consumption. However, modern agriculture is marked by selective breeding, resulting in domesticated crops that bear virtually no resemblance to their wild counterparts. Furthermore, recent studies have shown that transgenic crops are also found in nature. Matveeva and Otten (2019) found that 7% of dicots, a major group of flowering plants, were naturally transgenic, a much larger proportion than was previously known to undergo this process in nature.

Another reason for the difference in perception may be due to public underestimation of the scientific consensus surrounding the issue of genetic modification. This may be the result of journalistic “false balance” often found in media articles on the topic. The journalistic practice of presenting both sides of a controversy has been shown to give the false impression that both sides are equally supported. In a series of experiments, Koehler (2016) showed that false balance distorted the perception of participants regarding topics that had expert consensus.

While there are many possible factors behind this phenomenon, some common players are notably missing. Unlike other controversial SSIs, negative attitudes about GMFs do not fall neatly along political, demographic, or religious lines (Pew Research Center, 2016). Political affiliation is known to be a predictor of attitudes regarding climate change, and religion has been shown to be a factor in attitudes towards vaccination, but neither trend applies to negative GMF attitudes (Rutjens et al., 2018). Rather, research has shown that epistemic beliefs and emotions play a role in conceptualization and attitudes towards GMFs. The following review of the relevant literature will shed light on the interplay of these factors their effect on attitudes towards GMFs.

Informal Reasoning

According to Posner et al.'s (1982) theory of conceptual change, students evaluate new concepts based on both formal and informal, or intuitive, reasoning. They specifically cite epistemic commitments, beliefs concerning nature of knowledge, as a factor needed for conceptual change. Rönnebeck et al. (2016), in their literature review of inquiry methods, also noted a need for further research into the effects of epistemic considerations in inquiry-based strategies. In a study of preservice science teachers, Ozturk and Yilmaz-Tuzun (2017) found that informal reasoning hindered them from making strong arguments for their views about SSIs. Research into informal SSI reasoning has primarily focused on epistemic beliefs and construal-based reasoning.

Epistemic Beliefs

In their review of literature concerning SSI decision making, Fang et al. (2019) noted a trend of epistemic beliefs strongly influencing evidence-based reasoning. Epistemic beliefs inform epistemic cognition, the consideration of knowledge-related aspects and the way they are used (Greene et al., 2016). Epistemic cognition has also been linked to high academic achievement. Greene et al. (2018) performed a meta-analysis of literature related to epistemic cognition and found a small but significant correlation with academic achievement. Further analysis indicated that this increase is more strongly correlated with conceptual understanding and argumentation than with procedural activities, suggesting added gains for critical thinking skills (Greene et al., 2018). These findings are consistent with Posner et al.'s (1982) evaluation of epistemic beliefs as a component of the conceptual ecology. Muis (2007) built on Posner et al.’s theoretical foundation by proposing that such beliefs influence students' academic goals and serve as epistemological standards for cognition. Such beliefs typically go unstated by students but have profound impact on their ability to engage with scientific evidence.

Epistemic belief can be categorized using broad developmental categories. These stages were established in Perry's (1970) book about intellectual development among college students, resulting in the following Perry levels: dualist, multiplist, relativist, and dialectical. Dualists, also called absolutists, are seen to hold a more simplistic view that all questions have objective answers that are passively received from an intellectual authority. Multiplists and relativists are characterized by increasing levels of subjectivity, prioritizing opinions and perspectives over facts. Dialectical students take a stronger commitment to relativism, having become comfortable with uncertainty (Rosman & Mayer, 2018). Rosman and Mayer (2018) further distinguish evaluatism as a stage which straddles the line between absolutism and subjectivity by judging claims as tentatively certain or uncertain.

Other models of epistemic beliefs are more multidimensional, breaking down epistemic beliefs to discrete categories. Hofer and Pintrich (1997) proposed four belief categories; the former two (certainty knowledge and source of knowledge) describe beliefs about knowledge, while the latter two (simplicity of knowledge and justification of knowledge) describe beliefs about the process of knowing. Other models incorporate the ability of students to learn, as well as the speed of learning (Bullock, 2018; Schommer, 1990; Schraw et al., 2002). Along these factors, epistemic beliefs range from less constructivist to more constructivist. The view that knowledge is simple, acquired from authority figures, certain, and should be uncritically accepted is less constructivist. On the other hand, viewing knowledge as complex, actively constructed, tentative information that must be critically evaluated is more constructivist (Muis, Chevrier et al., 2018). Ozturk and Yilmaz-Tuzun (2017) used such categories to explore the relationship between epistemic beliefs and informal reasoning about nuclear power. In this study, 647 Turkish preservice science teachers were surveyed about their epistemic beliefs and made arguments to defend their views on nuclear power. The results indicated that belief that knowledge is absolutely certain, that the ability to learn is innate and only possessed by some, and that learning occurs quickly were correlated with poor argument construction (Ozturk & Yilmaz-Tuzun, 2017).

Furthermore, epistemic beliefs have been investigated as they differ within and between disciplines. Muis et al. (2016) sampled students from high school, undergraduate, and graduate school in order to understand their epistemic beliefs within and between academic domains. Self-report and interview data indicated differences between domain-general and domain-specific beliefs and that, while beliefs between domains were related, unique attributes still arose among them. For example, most students held absolutist beliefs concerning mathematics but multiplist beliefs about psychology and general knowledge. This suggests that students are more likely to deny certainty and be skeptical of experts in psychological domains than in mathematics. The results also indicated that most epistemic beliefs were informed by prior experience (Muis et al., 2016). However, one limitation of Muis et al.'s (2016) results is their reliance on self-report measures. Nonetheless, this pattern of experience as a basis for epistemic beliefs is consistent with Posner et al.'s (1982) evaluation of the conceptual ecology.

Epistemic beliefs inform the way an individual conceptualizes a particular topic, such as the theory of evolution. Borgerding et al. (2017) studied the relationship between epistemic beliefs and acceptance of the theory of evolution among 395 upper-level and first-year biology majors, as well as nonmajors. Through quantitative surveys, individual interviews, and a learning content questionnaire, the researchers evaluated students by Perry levels, year, and epistemic beliefs. They found that acceptance of evolution increased by year and age, as well as with more relativist and dialectical beliefs. The qualitative results contextualized this pattern based on their views of authority, religion, and the tentative nature of scientific findings (Borgerding et al., 2017). Epistemic beliefs clearly have a profound influence on students' attitudes towards SSIs.

Construal-based Reasoning

Epistemic beliefs also inform patterns of informal reasoning referred to as cognitive construals. These construals can serve as helpful linguistic shorthand, but often reinforce biological misconceptions (Richard et al., 2017). Because they are a form of intuitive reasoning, students do not often realize they are using construals. Therefore, to measure their use researchers must code students' answers to open-ended questions based on the presence of linguistic markers. These codes are then compared with the other variables at play, including agreement with misconceptions or attitudes about the topic at hand (Blancke et al., 2015; Coley & Tanner, 2015; Pope et al., 2017; Potter et al., 2017; Richard et al., 2017; Shtulman et al., 2020; Stern et al., 2018).

One example is anthropocentrism, wherein the student inappropriately applies human analogies to other organisms or distorts humans' place in nature. This has led some students to falsely apply concepts of choice and volition to processes like natural selection, particularly with antibiotic resistance in bacteria (Richard et al., 2017). Another typical construal is teleological thinking, which is based around a human bias towards causal explanations. Using teleological thinking, some students apply concepts of goal and purpose to natural processes that are actually driven by chance. Both of these construals have also been linked with student agreement with biological misconceptions (Coley & Tanner, 2015; Richard et al., 2017; Stern et al., 2018).

Another example is essentialism, the belief that an underlying property of an organism dictates its core identity (Coley & Tanner, 2015). Essentialists believe that this if this underlying property would be altered, it would undermine or redefine the identity of the organism. For example, if DNA is seen as the blueprint of life, without regard for the complications of genetic regulatory processes, the idea of genetic modification is seen as altering the subject's core essence rather than simply altering one aspect of an organism. This type of thinking has been linked to misconceptions about biology, namely regarding GMFs (Potter et al., 2017).

The use of such construals has been studied in the context of GMF attitudes, namely essentialism and teleological thinking. In an experiment assessing food preferences through parent-child conversations, the participants relied more heavily on moral language than on knowledge claims. One proposed reasoning for this reliance is that the use of genetic modification of food was seen as a violation of the essence (essentialism) and purpose (teleology) of the food products (Shtulman et al., 2020). The use of biotechnology to produce transgenic organisms is often seen as a corruption of the essence of the organism. When surveyed, more than half of respondents believed that a tomato modified with a fish gene would taste like fish. This essentialist view of transgenic organisms as bizarre hybrids has even been harnessed by anti-GMF activists in their promotional literature. Additionally, many hold the perception that altering the genome of an organism is an affront to the way crops are meant to be produced (Blancke et al., 2015). Those holding to this teleological view often accuse scientists of "playing God", a common phrase that has been closely associated with intuitive informal reasoning about biotechnology. In a study of Australian high school students, Pope et al. (2017) explored the impacts of religious beliefs on students' views of biotechnology SSIs, including GMFs, genetic screening, and cloning. The results indicated that students holding to a Christian worldview relied more heavily on intuitive reasoning than rational reasoning, specifically arguments marked by essentialism and teleology (Pope et al., 2017).

The inappropriate use of construals has also been shown to persist through formal science education. As with Borgerding et al.'s (2017) study, these examples have been studied in non-biology majors (NBM), entering biology majors (EBM), advanced biology majors (ABM) and in faculty. Research has found that most students studied across these groups showed similar use of essentialist reasoning (Potter et al., 2017; Richard et al., 2017). However, misconceptions among NBM were higher than in biology majors (Coley & Tanner, 2015). Furthermore, ABM showed only moderately lower agreement with misconceptions compared with NBM and EBM (Richard et al., 2017). A similar study in Switzerland found that 97% of participants agreed with at least one misconception and that there was consistent agreement with the use of construals in open-ended questions (Stern et al., 2018). Much like Coley and Tanner's (2015) results, Stern et al. (2018) found that there was no correlation between teleological and essentialist misconceptions. However, Coley and Tanner's (2015) results showed specific and precise connections between reasoning and misconceptions, suggesting that formal education might be unintentionally reinforcing such misconceptions and use of construal-based reasoning. On the other hand, Richard et al. (2017) found significant association across all construals for the groups studied, suggesting that formal training may not reify these trends.

Emotions

In addition to the use of cognitive construals, attitudes about GMFs are often shaped by emotional arguments (Blancke et al., 2015; Pope et al., 2017; Shtulman et al., 2020). Research in science education and communication has long focused on the "cold" cognitive and conceptual bases of students' views and decision-making about scientific issues (Engelmann et al., 2016;

Posner et al., 1982). However, recently more studies have addressed the importance of the “hot” factors of emotions and attitudes (Pekrun, 2006; Petty & Briñol, 2015; Rosman & Mayer, 2018). In this “warming” trend, more researchers are seeking to understand the relationship between beliefs, emotions, and attitudes related to SSIs (Leonard et al., 2014).

Emotions are complex, multifaceted psychological processes. Science education particularly interfaces with epistemic emotions, which result from information-based appraisals, and can inform future educational efforts (Muis, Chevrier et al., 2018). Emotions may be general across academic domains, specific to a particular academic domain, or specific to a particular topic. While science education is largely concerned with topic-specific emotions, all three categories show interplay with one another. In contrast to emotions, attitudes are overall evaluations of a subject (i.e. object, topic, person, or event). Attitudes are informed by emotions, and can be valenced, or oriented, either positively or negatively with regard to the subject (Maio & Haddock, 2010). Emotions and attitudes are dictated by a number of factors, including individual values, which play an important role in attitudes towards SSI (Fang et al., 2019).

Epistemic Emotions

Epistemic emotions include curiosity, surprise, enjoyment, anxiety, confusion, frustration, and boredom (Pekrun et al., 2017). Such academic emotions are largely driven by the appraisals of control and value, according to the control-value theory of emotion (Pekrun, 2006). Muis et al. include the novelty and complexity of new information as antecedents to emotions. Additionally, the achievement or impasse of an academic goal also has a role in informing emotion (Muis, Chevrier et al., 2018).

Emotions also result in several consequences, which can facilitate or hinder future learning. These consequences include planning and setting of goals, motivation on future assignments, cognitive strategies, learning outcomes, and revisions to prior beliefs (Muis, Chevrier et al., 2018). As part of the control-value theory of emotion, Pekrun (2006) posited that emotions could be categorized by their valence as positive or negative, and by their role in activating or deactivating the student towards future action. For example, enjoyment is a positive activating emotion, while relief is a positive deactivating emotion. Similarly, anger is a negative activating emotion, while boredom is a negative deactivating emotion (Pekrun, 2006).

The influence of emotions on learning strategies and outcomes has also been measured. Chevrier et al. (2019) found that positive epistemic emotions predicted more effective learning strategies. Specifically, curiosity resulted in greater metacognitive self-reflection and surprise resulted in more critical thinking and less simple rehearsal (Chevrier et al., 2019). Muis et al. (2015) also found that positive epistemic emotions positively correlated with deeper processing strategies and critical thinking. On the other hand, negative emotions correlated negatively with deep processing strategies, and positively with shallow strategies, such as simple rehearsal or memorization (Muis et al., 2015). While Chevrier et al. (2019) relied on self-report measures, Muis et al. (2015) measured these emotions using a novel instrument, called the Epistemically-Related Emotion Scales (EES). This reliable and valid instrument is easier, less invasive, and more cost-effective than more observational alternatives, and allows for easier quantification of emotions (Pekrun et al., 2017).

Emotions and Conflict

Early models of decision making were based on a philosophy that viewed such decisions as a simple analytical calculation (Posner et al., 1982). However, research from physiological studies and clinical psychology demonstrate that emotional reactions tend to diverge from conceptual assessment, particularly under conditions of risk or uncertainty. People evaluate risks both cognitively and emotionally, but the two differ greatly. Emotional evaluations in the face of perceived risk, namely fear, do not require significant cognitive processing, or even an awareness of what the person is afraid of. Emotions are also subject to imagery and imagination, and can result in a discrepancy between the emotional and cognitive evaluations of risk (Loewenstein et al., 2001). This pattern is particularly true of GMF safety, which involves assessment of both benefits and risks. While a significant portion of the U.S. public perceives GMFs as risky, a sizeable majority also recognize their benefits, including capability to increase the supply of food and make it more affordable (Funk, 2020). In a study of U.S. adults, GMF rejection was primarily linked with perceptions that they result in allergic reactions or illness. This study was carried out in an agricultural state, which makes the degree of opposition more surprising (Rose et al., 2020).

It is evident that the role of emotions in GMF attitudes is pivotal, particularly when conflicting claims must be evaluated. Such evaluations also rely on epistemic beliefs. Bendixen and Rule (2004) further built on Posner et al.'s (1982) theoretical foundation in their integrated model of epistemic beliefs. They noted that incongruity arises when learners encounter information that is inconsistent with their beliefs, which often results in negative epistemic emotions. Such emotions are often viewed as harmful to learning goals, but some have argued that such negative emotions can actually yield positive results. D'Mello and Graesser (2012) note that these discrepancies cause cognitive disequilibrium, resulting in confusion, a negative emotion. This confusion then has the opportunity to inform epistemic goals and, if resolved, results in positive epistemic emotions. However, if the confusion remains unresolved, it can result in further negative emotion, such as frustration (D'Mello et al., 2014; Muis, Chevrier et al., 2018).

The relationship between epistemic beliefs and emotions has been documented by Rosman and Mayer (2018), who compared epistemic emotions with absolutist, multiplist, and evaluatist beliefs in students. Their findings suggested that evaluatism is correlated with lower negative epistemic emotions. Students with stronger evaluatist indicators showed lower levels of confusion, surprise, and frustration when tasked with resolving conflicting claims. On the other hand, students with stronger absolutist indicators showed higher levels of these negative emotions (Rosman & Mayer, 2018).

By addressing the role of beliefs and emotions in evaluating conflicting information, research has also demonstrated that it improves learning strategies and outcomes. The dimensions of belief most commonly studied are the certainty, simplicity, source, and justification of knowledge. Muis et al. (2015) studied the interplay of beliefs and emotions using instruction about climate change, which was based on texts that differed according to these belief dimensions. Their results showed that addressing two dimensions (justification and complexity) predicted positive emotions of enjoyment and curiosity. However, they found that all four dimensions predicted lower levels of negative emotions. As a result, if a student believes that justifying claims about climate change requires critical evaluation of multiple sources, they are likely to show greater levels of curiosity and enjoyment and lower levels of boredom. Additionally, when students grasped the complexity of knowledge claims, along with the tentativeness and active construction of knowledge, they showed lower levels of confusion, anxiety, frustration, and boredom. These positive emotions were correlated with more effective learning strategies and better academic outcomes (Muis et al., 2015).

These findings were further validated by Trevors et al. (2017), who also tested students epistemic beliefs, emotions, and learning outcomes. In this study, participants were assessed for epistemic beliefs and emotions through the process of reading three conflicting texts about climate change and writing summaries of them. The findings support the impact of beliefs on emotions, which then influence learning outcomes. For example, students who viewed scientific knowledge as passively acquired responded with confusion to conflicting information, resulting in impairments during the experiment. On the other hand, students who view the science as a process of inquiry responded with greater curiosity, which was shown to expedite learning (Trevors et al., 2017). The findings of Chevrier et al. (2019) further confirmed this pattern. As with the prior studies, students were evaluated for epistemic beliefs and emotions, and exposed to conflicting information about climate change. Students with more constructivist beliefs at the outset of the experiment reported greater degrees of curiosity and less surprise and boredom. The emotional response also correlated with more critical thinking and higher learning achievement (Chevrier et al., 2019).

Improvement of critical thinking was also observed when students were presented with conflicting information about GMFs. Muis et al. (2021) studied the role of epistemic cognition and emotions on critical thinking in undergraduate students. For this study, participants were evaluated for knowledge on GMFs, as well as their epistemic beliefs. They were then presented with information on the advantages and disadvantages of GMFs, assessed for epistemic emotions, and wrote an argumentative essay. While the results indicated complex interactions between these factors, a few trends stand out. Those with more constructivist beliefs about the complexity of knowledge, justification of findings, and complexity of knowledge about GMFs indicated more positive emotions. The acknowledgment of knowledge as complex and uncertain was also predictive of critical thinking. Furthermore, while frustration in participants predicted low critical thinking, confusion and anxiety actually predicted high critical thinking, suggesting that confusion served to motivate further learning (Muis et al., 2021). This finding is consistent with previous findings (D'Mello et al., 2014; D'Mello & Graesser, 2012; Muis, Chevrier et al., 2018).

The proposed reason for this relationship lies in the alignment of epistemic beliefs with learning tasks. When students' epistemic beliefs and the epistemic nature of the learning task are well aligned, this results in more positive emotions such as curiosity. This congruity allows the students to be well equipped to learn due to greater perceived control of their own learning. In contrast, poor alignment of beliefs and learning task results in incongruity and a loss of perceived control (Muis et al., 2015; Trevors et al., 2017). However, the novelty of the information can also increase the perceived value to the student, which can have a positive impact on emotion, consistent with Pekrun's (2006) control-value theory of emotion.

Conceptual & Attitude Change

Because the goal of science education is to increase scientific literacy, this often requires prior conceptions to be replaced. The correction of prior misconceptions to more closely align with scientific information is known as conceptual change (Vosniadou, 2013). In their theory of conceptual change, Posner et al. (1982) posit that prior concepts are only replaced when there is sufficient pressure to change and when the conditions of the conceptual ecology are ready. This process includes correcting misconceptions, as well as a shift towards more constructivist epistemic beliefs, which in turn affect emotion and learning (Muis et al., 2015). Conceptual change has the potential to influence a person's attitude towards the subject at hand. When the evaluation shifts in valence towards or away from the positive or negative direction, this is referred to as attitude change (Maio & Haddock, 2010). A commonly used instrument for conceptual change is a refutation text, which directly addresses common misconceptions

(Broughton et al., 2013; Heddy et al., 2017; Muis, Sinatra et al., 2018; Muis et al., 2020; Thacker et al., 2020; Trevors et al., 2021; Trevors et al., 2016). Expository texts provide a broad description, more similar to a textbook reading, and do not evoke as much epistemic judgment as refutation texts (Lombardi, Danielson, et al., 2016). Persuasive texts present the benefits and drawbacks of a particular topic, typically with the goal of persuading the reader. These have also been shown to prompt attitude change (Sinatra et al., 2012).

Conceptual Change

Strong, negative attitudes towards controversial topics like GMFs are often attributed to a knowledge deficit on the topic. This deficit model posits that public resistance could be countered by simply providing relevant information (Simis et al., 2016). Put another way, increasing knowledge should drive conceptual change, resulting in attitude change. Some findings seem to support this model, such as a national survey of U.S. adults that showed the strongest negative attitudes towards GM food correlate with weak knowledge but strong confidence (Fernbach et al., 2019). European studies have also shown that general science knowledge is a strong predictor of positive attitudes towards GM food (Rutjens et al., 2018). An international meta-analysis also found a small, but significant correlation between general knowledge and attitudes towards science. However, while general knowledge was not predictive of positive attitudes towards GMFs in particular, knowledge of biology and biotechnology was (Allum et al., 2008; McPhetres et al., 2019). Such findings are reminiscent of the Dunning-Kruger effect, wherein an individual's confidence is disproportional to their actual understanding of a topic. According to this effect, people often overestimate their own understanding of unfamiliar topics and lack the cognitive ability to acknowledge the limits of their knowledge, leading to erroneous conclusions. Theoretically, as knowledge increases, so should the understanding of the complexity of the issue (Kruger & Dunning, 1999).

Certain findings are consistent with the deficit model, including a study in which undergraduate students showed improved understanding of, and more positive attitudes towards, GMFs. In this study, the non-science major undergraduate students volunteered for a peer-teaching program in which they were tasked with teaching high school students about GM technology and food. By the end of the study, 97% of the participants held a favorable view of GMFs, up from less than half at the beginning of the study. Additionally, the 43% of participants that initially viewed GMFs as harmful disappeared to none by the end of the study. Surveys indicated that most of the participants attributed their knowledge gain to the peer-teaching. Furthermore, the most significant factor in their attitude change was the comparison of genetic modification with selective breeding, the process by which humans have intentionally and drastically altered wild organisms since the dawn of agriculture (Chrispeels et al., 2019). In the aforementioned surveys of GMF safety, the trend of rapidly increasing skepticism grew primarily among those with lower levels of science knowledge; those with higher degrees did not become significantly more opposed (Kennedy et al., 2018). Similarly, some international studies indicate that a lack of understanding in GM technology is predictive of skepticism. In particular, one longitudinal study found that an extended unit on GM technology resulted in increased positive attitudes and a decreased assessment of GMFs as risky (McPhetres et al., 2019). Such findings seem to support the deficit model.

However, the deficit model does not account for all the factors that can influence attitude change, such as demographics, worldview implications, political factors, self-concept, prior background knowledge, epistemic beliefs, and emotions. For this reason, attempts to test this model have yielded inconsistent results. For example, Kahan et al. (2012) used a nationally representative sample of U.S. adults to compare degree of science literacy and concern about climate change. While the deficit model would predict a direct relationship, the opposite was found. Those with the highest degree of literacy and technical reasoning actually showed the greatest degree of cultural polarization on the issue. Specifically, they were motivated by the personal interests of those they were most closely associated with (Kahan et al., 2012). On the other hand, other studies find conflicting results. That same year, Sinatra et al. (2012) assessed college students' attitude about climate change before and after reading a persuasive text, which used provocative language to assert pros and cons, but did not attempt to refute common misconceptions. The results indicated that students became more concerned about climate change and were more willing to act in mitigating its effects over the course of the study (Sinatra et al., 2012).

Similarly, Potter et al. (2017) examined college students' use of evidence to answer questions about GMFs. The results showed that students rarely cited biological evidence in their responses, despite the biology majors having shown competence with the necessary concepts. The results also indicated that the correct use of such data was closely correlated with accurate scientific conceptions and strong reasoning about the topic, as measured by the views of faculty and experts on the topic. Therefore, while many students had the necessary tools to support their conceptual understandings scientifically, they instead relied on informal reasoning such as essentialist rationales. As such, many were unwilling or unable to use their tools to correct their own misconceptions (Potter et al., 2017). These results are consistent with Posner et al.'s (1982) evaluation that the conceptual change requires dissatisfaction with a prior explanation, which was not broadly established in Potter et al.'s (2017) investigation.

Such findings suggest that the deficit model is limited in its explanatory power. Critics claim the model is too rigid, unable to account for the complex interplay of factors involved in conceptual and attitude change (Simis et al., 2016). However, it is still applied in science education and communication, often attempting to influence public perceptions and policy. The deficit model may persist because most scientists lack any significant public communication training. Another potential reason for its tenacity is that scientists are trained to set aside external influences as much as possible and draw conclusions from the data. While this is good scientific practice, it is not safe to assume that the general public is similarly motivated (Simis et al., 2016). For these reasons, it is crucial that scientific information be presented in an accessible and understandable way, with considerations made for the other factors influencing conceptual and attitude change (McPhetres et al., 2019).

Because SSIs tend to reflect situations where there is no obvious solution, students must utilize discernment to balance multiple concerns. In many ways, this mirrors the nature of scientific discovery as a nuanced and iterative process. Therefore, nuanced views tend to reflect the multifaceted nature of the problem at hand, whereas oversimplified views tend to be indicative of limited understanding. While this has not been explored extensively in the research literature, Dinsmore et al. (2017) studied view complexity regarding GMFs through an intervention of different types of texts: persuasive, informative, and narrative. College students were asked open-ended questions before and after the intervention, and their responses were categorized by complexity based on respondents' use of evidence. While the results did not pass the threshold for statistical significance, informative and narrative text correlated with modest increase in complexity. There were also unexpected results. For example, persuasive text showed a decrease in complexity. This unexpected result may have been due to participant fatigue

(Dinsmore et al., 2017). However, another possibility is the backfire effect, a phenomenon that occurs when attempts to correct a misconception instead cause deepened commitment to it (Nyhan & Reifler, 2010).

First described in political sociology, the backfire effect is more common in controversial topics that are tied deeply to one's identity (Nyhan & Reifler, 2010). People have also been shown to be more likely to uncritically accept arguments favorable for their own position, while being more skeptical of arguments unfavorable to it. Therefore, what begins as confirmation bias can result in belief polarization, which occurs when the same information presented to both sides in a conflict results in further divergence between the two sides. While the backfire effect is often observed in political communication, it has also been documented in peoples' response to controversial SSIs, including vaccinations, climate change, and GMFs. This effect should be considered when attempting to correct misconceptions for such topics (Lewandowsky et al., 2012).

Another important factor in conceptual change is the role of epistemic judgments. Lombardi, Nussbaum, et al. (2016) built on Posner et al.'s (1982) conceptual change model by describing the role of plausibility judgments in conceptual change. According to this model, people pre-process the validity of new information based on their background knowledge, the complexity and perceived certainty of the claims, and the perceived credibility of the source. These implicit judgments can cause misconceptions to persist due to their perceived plausibility (Lombardi, Nussbaum, et al., 2016). Epistemic judgments have also been experimentally shown to facilitate conceptual change. By using a refutation text to address misconceptions about climate change, Lombardi, Danielson, et al. (2016) found that such texts resulted in greater epistemic judgment and conceptual change than expository texts. Participants that more critically evaluated the plausibility of the claims presented to them demonstrated greater knowledge acquisition (Lombardi, Danielson, et al., 2016). These judgments are critical in issues with a significant plausibility gap, such as with GMFs. Furthermore, going forward into what some have called the "post-truth" era, misinformation is being increasingly weaponized for a variety of purposes. As such, it is imperative that science education consider such plausibility judgments when attempting to correct misinformation (Sinatra & Lombardi, 2020).

Trevors et al. (2016) sought to explore the cause of the backfire effect in response to GMFs by correcting some common misconceptions. Participants answered questions about dietary self-concept before reading either an expository or a refutation text about GMFs. Then, they reported emotions, attitudes, and answered a knowledge assessment. The results suggested that refutation text, combined with factors of self-concept, resulted in negative emotions. These emotions negatively impacted knowledge acquisition and attitude through the study. The authors propose that this can occur when the refutation of prior conceptions causes the participant to see their self-concept as threatened, leading to a defensive response of either ignoring the information or relying on prior knowledge that confirms prior attitudes (Trevors et al., 2016). The backfire effect is an example of both the risks of refutation texts and the shortcomings of the deficit model. Conceptual change is also influenced by epistemic and emotional factors and is closely associated with attitude change.

Emotions & Attitude Change

The cognitive and emotional factors that influence students' views of SSIs have largely been investigated separately in education research, following from the theory of conceptual change (Posner et al., 1982) and the control-value theory of emotion (Pekrun, 2006). However, some have described the interplay of these factors, particularly as they relate to controversial topics. Several studies have explored the interplay of epistemic beliefs and emotions during conceptual and attitude change.

Conceptual change has been shown to result in emotional changes. Heddy and Sinatra (2013) described one such emotional effect following students' conceptual change surrounding evolution. In this study, Heddy and Sinatra sought to use an educational model to help students grasp the real-life relevance of evolution, a topic that has long been known to cause anxiety in learners. They found that by correcting misconceptions, students experienced an emotional change. Specifically, they reported higher levels of enjoyment and lower levels of anxiety (Heddy & Sinatra, 2013). This is likely due to the emotional response to resolving cognitive dissonance (Posner et al., 1982). According to D'Mello and Graesser (2012), discrepancies between prior conceptual understanding and new information lead to disequilibrium and confusion. In fact, confusion is one of the most frequently encountered epistemic emotions during learning (Muis, Chevrier et al., 2018). D'Mello et al. (2014) argue that this confusion is an important factor for complex learning. When this confusion is resolved through conceptual change, it results in positive epistemic emotions. However, continued confusion results in negative epistemic emotions, such as frustration (D'Mello & Graesser, 2012).

Studies have also shown that emotional factors can also influence conceptual change. Building on Posner et al.'s (1982) theory of conceptual change, Dole and Sinatra (1998) posited that conceptual change is most likely to occur with deep engagement, which is driven by motivation and emotions. In a fascinating study, Trevors et al. (2021) explored the effects of induced emotions on participants' willingness to revise misconceptions about vaccines. The researchers induced either positive or negative emotions, participants watched clips from either the improvisational comedy show *Whose Line Is it Anyway?* or the death scene from *The Lion*

King. Paradoxically, participants with negative emotions were more likely to revise their conception of vaccines than those with positive emotions. Negative prior emotions are thought to facilitate accommodation because they are more congruent with the revision of knowledge (Trevors et al., 2021). While the study assessed prior emotions rather than epistemic emotions, the results are still relevant for science education. Along these lines, Muis, Sinatra, et al. (2018) tested the effects of refutation text on epistemic emotions during conceptual change, particularly of value students placed on a topic. They found that when students placed high value on the topic, the refutation text yielded greater surprise, but found the opposite relationship with expository text. They also found that refutation texts predicted greater critical thinking and elaboration strategies, as well as helping foster conceptual change when compared to expository text. The positive emotions of surprise and curiosity sparked by reading the refutation text resulted in greater critical thinking, elaboration, and correction of misconceptions (Muis, Sinatra et al., 2018).

While the interplay between conceptual and emotional factors have been explored in science education, fewer studies have also incorporated attitude change. Sinatra and Seyranian (2016) factored the role of emotions into their attitude/conceptual change framework. This two-by-two model considers an individual's advocacy for a particular topic (pro vs. con) as well as the accuracy of their conceptions regarding the topic (justified vs. unjustified). Four profiles emerge, which are pro-justified, pro-unjustified, con-justified, and con-unjustified. According to this framework, correcting misconceptions can result in a shift from unjustified to justified conceptions. This correction can also inform an attitudinal shift from opposition to support, which is mediated by epistemic emotions. Therefore, it seems that conceptual change informs emotional change, which in turn dictates attitudinal change.

This pattern is supported by several empirical findings (Muis et al., 2020; Thacker et al., 2020). For example, Broughton et al. (2013) assessed the role of emotions in mediating the reactions of fifth and sixth graders to the reclassification of Pluto from planetary status to a dwarf planet. The researchers used a refutation text to correct common misconceptions, which resulted in a marked increase in positive emotions and attitude change. Therefore, positive emotions were shown to result in more positive attitudes (Broughton et al., 2013). In another study, Heddy et al. (2017) demonstrated a similar relationship in college students' views of GMFs. In this study, a refutation text was also used, which corrected misconceptions and generally resulted in improved emotions and attitudes about the topic compared to the control group. Thus, emotions are understood to act as mediators between conceptual change and attitudes, a relationship which was earlier theorized by Petty and Briñol (2015). They posited that this mediating effect was influenced by the extent of student elaboration on, or engagement with, the topic. If elaboration is low, attitudes are simply modified towards the valence of the emotion, either positive or negative. On the other hand, if elaboration is high, emotions can act as arguments within the thought process. If elaboration were unconfined, emotions would influence the extent of student engagement with the topic. Moreover, Petty and Briñol (2015) proposed a timing factor, whereby encountering an emotion before deep thought would bias the thinker in that direction. On the other hand, emotions encountered after deep thought cause the thinker to reflect and question their confidence about the conclusions they had drawn.

These studies are necessary steps towards grasping the interplay of conceptual understanding, emotions, and attitudes (Broughton et al., 2013; Heddy et al., 2017). However, their linear nature does not fully address the nuanced relationship that exists among such factors. Op 't Eynde and Turner (2006) posited a more dynamic understanding of cognitive and attitudinal factors, which allows for feedback within the system. This model also allows for a more nuanced view of the role of individual differences and social factors in conceptual and attitudinal change. This is consistent with the findings that dietary self-concept predicts negative emotional response to GMFs (Trevors et al., 2016). An individual's self-concept is comprised of deeply held beliefs, including epistemic beliefs. Social identity is another factor of one's self-concept, and has been shown to predict attitudes towards controversial scientific findings (Kahan et al., 2012; Nauroth et al., 2015). In an effort to contribute to a more nuanced understanding of these factors, Nadelson et al. (2018) built on Sinatra and Seyranian's (2016) framework in developing their Dynamic Model of Conceptual Change (DMCC). According to the DMCC, conceptual change occurs in stages, including the subject's interaction with the external message, consideration, and engagement with it through dynamic contemplation. If the message is received and processed, conceptual change can occur. However, there are varying degrees of potential change, from deep transformation to dormant consideration. Each step in this process is influenced by epistemic factors and emotional reactions, which affect long-term acceptance and attitude towards the topic (Nadelson et al., 2018).

The interplay between epistemic beliefs and emotions with conceptual and attitude change are particularly apparent in the study of views of GMFs. In a longitudinal study, McPhetres et al. (2019) demonstrated a link between conceptual change and improved attitudes towards GMFs. Following a five-week unit on GM technology, participants reported more positive attitudes towards GMFs. This is consistent with the findings of Chrispeels et al. (2019). Heddy et al.'s (2017) study supported this relationship, and further demonstrated the mediating role of epistemic emotions in these attitudes using a refutation text. This text was then used in a large international study, which sought to explore the impact of refutation and persuasive texts on attitudes towards GMFs. In this study, undergraduate students were assessed for prior attitudes before reading the refutation text and persuasive texts highlighting either the advantages of GMFs, the disadvantages of GMFs, or both. Then, they were assessed for epistemic emotions and topical knowledge. Participants presented with the advantages showed more knowledge gains and a more positive attitude towards GMFs. Further analysis indicated that positive attitude change was mediated by positive emotions, including joy, hope, enjoyment, and curiosity. On the other hand, frustration drove more negative attitudes (Thacker et al., 2020).

Thacker et al.'s (2020) study indicated that positive messages about GMFs were more effective than negative messages at driving conceptual and attitude change. However, it did not establish the mechanism behind these changes. To explain this process, Muis et al. (2020) proposed that epistemic judgments and emotions were at play. In this study, undergraduate students were presented with one of four combinations of either a refutation or expository text paired with a persuasive text, presenting either positive or negative arguments about GMFs. The texts were based on those used previously by Heddy et al. (2017) and Thacker et al. (2020). Participants that read a refutation text paired with a positive persuasive text demonstrated increased epistemic judgment and conceptual change, reappraising more misconceptions about GMFs. The results also confirmed prior findings that positive and negative emotions predicted change towards more positively and negatively valenced attitudes respectively (Muis et al., 2020). Muis et al. (2021) further established that epistemic beliefs further impacted epistemic emotions and learning about GMFs. After being assessed for prior knowledge and epistemic beliefs, undergraduate students were presented with the aforementioned refutation text along with the pros and cons of GMFs. They were then assessed for epistemic emotions before writing an argumentative essay. The results indicated that beliefs about the complexity, source, justification, and certainty of knowledge variably affected epistemic emotions and critical thinking (Muis et al., 2021).

Summary

The purpose of this review was to evaluate the literature concerning the impact of students' preexisting beliefs on their views of socio-scientific issues. Because the goal of science education is to promote conceptual reasoning and the application of knowledge, it often requires conceptual change on the part of the student. The process of learning elicits emotional responses that can further influence attitudes related to learning. Much research has examined the role of conceptual reasoning in scientific literacy, which has been fostered through a variety of interventions. However, other studies have shown that the complexity of students' views regarding such issues is also prone to influence from personal or epistemic factors. Such informal reasoning includes epistemic beliefs and commitments as well as the use of construal-based reasoning, such as teleological, essentialist, or anthropocentric patterns. These construals are particularly influential when students evaluate SSIs. Other research has examined the role of emotions in mediating the impact of epistemic beliefs on learning outcomes, as well as attitudinal changes surrounding topics.

However, the strongest studies are those that seek a holistic understanding of these factors, rather than exploring them in isolation. People are complex, and make decisions based partly on beliefs and emotions, not simply on conceptual understanding. The literature indicates that more constructivist beliefs about the nature of knowledge can yield more positive and activating emotions, resulting in positive attitudes towards scientific topics. While training future scientists is a goal of science education, the main purpose should be training scientifically literate citizens. As scientific issues gain increasing public scrutiny, it is more important than ever that average adults be equipped to engage with these topics holistically.

The relationship between epistemic beliefs, emotions, and attitudes towards SSIs is dynamic and ripe for future exploration (Sinatra & Seyranian, 2016). While some research has investigated these factors, the interaction between each factor has not been studied. The purpose of the present study is to address the research gap with an emphasis on GMFs. By considering the impact of epistemic beliefs and emotions on attitudes towards GMFs, this study has significant implications for both educational research and practice.

CHAPTER THREE: METHODS

Overview

The purpose of this study is to examine the relationship between epistemic beliefs, epistemic emotions, and attitudes towards GMFs among undergraduate students. This chapter begins with an explanation of and rationale for the non-experimental correlation design that were used to carry out this study. Next, the research questions are stated, along with their corresponding null hypotheses. Then, the setting and participants are described, including demographic data. The following section describes the instruments that were used to measure the predictor and criterion variables in depth, and reports reliability considerations. Detailed study procedures are then described for the collection and analysis of data.

Design

The purpose of this quantitative, predictive correlational study is to investigate the relationships between epistemic beliefs, epistemic emotions, and attitudes towards GMFs. Because the function of a quantitative correlational research design is to examine relationships between variables, this study utilized a quantitative, non-experimental, correlation design. Moreover, correlational research allows for evaluating associations between several variables, making it ideal for this study. However, the causality of these associations cannot be conclusively demonstrated in a correlational design because of the possibility of additional confounding factors. To test the causality, an experimental setup should be used, wherein participants are randomly assigned to treatment and control groups in an effort to account for potential confounding factors (Gall et al., 2007).

Correlational designs have an established history of use in educational research related to SSIs (Muis et al., 2015; Potter et al., 2017; Richard et al., 2017). Studies of the factors influencing GMF attitudes in particular have also relied heavily on correlational designs (Heddy et al., 2017; McPhetres et al., 2019; Muis et al., 2020; Thacker et al., 2020). Some studies have utilized control groups and longitudinal designs to establish a causal relationship between variables (Chrispeels et al., 2019; McPhetres et al., 2019). However, this is beyond the scope of the present study.

In this study, one of the predictor variables is epistemic beliefs. Epistemic beliefs are those concerned with the nature of knowledge and its acquisition (Schraw et al., 2002). This variable was measured using Schraw et al.'s (2002) Epistemic Belief Inventory (EBI).

One of the criterion variables in this study is attitudes towards GMFs. Attitudes are general appraisals or judgments of a subject, GMFs in this case (Heddy et al., 2017). This variable was measured using Heddy et al.'s (2017) Attitudes about GMFs survey.

Epistemic emotions are those related to the generation of knowledge and of learning (Pekrun et al., 2017). In this study, epistemic emotions served as a predictor variable for Research Question 3, but as a criterion variable for Research Question 1. Epistemic emotions were measured using the Epistemically-Related Emotion Scales (EES) (Pekrun et al., 2017).

Research Questions

RQ1: Do *epistemic beliefs* of undergraduate students predict *epistemic emotions* following refutation of common misconceptions about GMFs?

RQ2: Do *epistemic beliefs* of undergraduate students predict *attitudes towards GMFs* following refutation of common misconceptions?

RQ3: Do *epistemic emotions* of undergraduate students predict *attitudes towards GMFs* following refutation of common misconceptions?

Hypotheses

The null hypotheses for this study are:

$H_0$1: There is no statistically significant predictive relationship between the predictor variable, *epistemic beliefs* of undergraduate students, as measured by the Epistemic Belief Inventory, and the criterion variable, *positive epistemic emotions*, as measured by the Epistemically-Related Emotion Scales following refutation of common misconceptions about GMFs.

$H_0$2: There is no statistically significant predictive relationship between the predictor variable, *epistemic beliefs* of undergraduate students, as measured by the Epistemic Belief Inventory, and the criterion variable, *negative epistemic emotions*, as measured by the Epistemically-Related Emotion Scales following refutation of common misconceptions about GMFs.

$H_0$3: There is no statistically significant predictive relationship between the predictor variable, *epistemic beliefs* of undergraduate students, as measured by the Epistemic Belief Inventory, and the criterion variable, *attitudes towards GMFs*, as measured by the Attitudes about GMFs survey following refutation of common misconceptions about GMFs.

$H_0$4: There is no statistically significant predictive relationship between the predictor variable, *positive epistemic emotions* of undergraduate students, as measured by the Epistemically-Related Emotion Scales, and the criterion variable, *attitudes towards GMFs*, as measured by the Attitudes about GMFs survey following refutation of common misconceptions about GMFs.

$H_0$5: There is no statistically significant predictive relationship between the predictor variable, *negative epistemic emotions* of undergraduate students, as measured by the

Epistemically-Related Emotion Scales, and the criterion variable, *attitudes towards GMFs*, as measured by the Attitudes about GMFs survey following refutation of common misconceptions about GMFs.

Participants and Setting

The target population for this study was undergraduate students in the United States, particularly those taking introductory science courses. The sample was drawn from undergraduate students at a Christian university located in central Virginia accredited by the Southern Association of Colleges and Schools (SACS). Participants for this study must meet the requirements of being in non-biological majors, having never taken an introductory biology course, and being currently enrolled in an introductory science course. Eligible participants were drawn from a convenience sample of students in eight courses during the fall semester of 2021: Principles of Biology, General Biology I, Principles of Human Biology, Elements of General Chemistry, General Chemistry I, Advanced General Chemistry I, Essentials of General and Organic Chemistry, and General Physics I. An email was sent to all students in these courses that met the study requirements, explaining the nature of the study and inviting students to be participants.

From this population, $N = 78$ participants were drawn. This sample size exceeded the minimum required when assuming a medium effect size in a correlational study at the .05 alpha level, which is $N = 66$ (Gall et al., 2007). Of the survey respondents, 39 (50%) were male students, 38 (49%) were female students, and 1 (1%) selected “other”. Participants were drawn from each grade level, including freshmen 37 (47%), sophomores 30 (38%), juniors 10 (13%), and seniors 1 (1%). Age demographics showed that all 78 (100%) of the participants were between 18 and 23 years of age. Ethnicity data showed that 5 (6%) were Hispanic, 3 (4%) were

Asian, 5 (6%) were black/African American, 1 (1%) was Native Hawaiian/Pacific Islander, and 68 (87%) were white/European American. Religious demographics showed that 75 (96%) participants were of Christian affiliation, 1 (1%) of Muslim affiliation, and 2 (3%) identified as “other”.

Instrumentation

Epistemic Belief Inventory

The Epistemic Belief Inventory (EBI) is an instrument that was developed by Schraw et al. (2002) to assess five factors of epistemic beliefs: omniscient authority, certain knowledge, quick learning, simple knowledge, and innate ability. This instrument is a modification of the Epistemological Beliefs Questionnaire (EBQ), developed by Schommer (1990), wherein content validity was established through screenings with educational psychology experts. The EBQ has also given rise to other instruments, such as the Discipline-Focused Epistemological Beliefs Questionnaire (DFEBQ) (Hofer, 2000; Muis et al., 2016). Like the EBQ, the EBI was designed for use with undergraduate college students, making it appropriate for this study. However, Schraw et al. (2002) built on the EBQ by clarifying the omniscient authority factor, shortening the instrument from 32 questions to 28 and improving efficiency. The resulting factors were also more homogenous, resulting in greater criterion validity. The EBI was chosen for this study based on these improvements. The EBI has also been used in several other studies (Frederick et al., 2012; Ismail, 2016; Neely, 2016).

The instrument consists of five dimensions based around the five factors of epistemic beliefs: Omniscient Authority, Certain Knowledge, Quick Learning, Simple Knowledge, and Innate Ability. Each question is on a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The Omniscient Authority dimension includes five questions and a sub-scale reliability of Cronbach's alpha .65. The Certain Knowledge dimension includes six questions and a subscale reliability of Cronbach's alpha .63. The Quick Learning dimension includes five questions and a sub-scale reliability of Cronbach's alpha .60. The Simple Knowledge dimension includes six questions and a sub-scale reliability of Cronbach's alpha .66. The Innate Ability dimension includes six questions and a sub-scale reliability of Cronbach's alpha .63. Reliability for the EBI was established in a study of 160 undergraduate students. There is a total of 28 questions, with a total score that ranges from 28 to 140. The higher the score, the more naïve the participant's beliefs about that particular dimension of knowledge, or knowledge as a whole (Schraw et al., 2002).

Self-report measures for epistemic beliefs have suffered from persistent shortcomings, drawing heavy criticism in the literature (DeBacker et al., 2008; Muis et al., 2016). In particular, subscale reliability scores for both the EBQ and the EBI are commonly found to be questionable or poor. Some studies using the EBQ, generally performed in western countries like the United States and the Netherlands, have had questionable to poor subscale reliability scores (Otting et al., 2010; Schommer, 1993). Others have yielded acceptable Cronbach's alpha scores, such as those performed in Fiji and Turkey (Mehdinezhad & Bamari, 2015; Phan, 2008). The EBI also suffers from mixed subscale reliabilities, even within the United States. Moreover, some studies have reported a combination of acceptable and questionable Cronbach's alpha values (Bendixen et al., 1998; Neely, 2016). DeBacker et al. (2008) found consistently questionable reliability scores, and also noted that their study with larger sample sizes yielded smaller Cronbach's alpha scores than those found in the literature. However, some studies have yielded promising reliability values in the acceptable range in both Singapore and the United States (Frederick et al., 2012; Lim & Chapman, 2020). Despite irregular subscale reliabilities, the EBI was chosen for this study due to its validity and appropriateness for addressing the research questions. Furthermore, because the research questions do not evaluate subscales. For the current study, the EBI demonstrated a cumulative Cronbach's alpha of .73.

This instrument takes approximately 20 minutes to complete (Schraw et al., 2002). As part of this study, the instrument was administered via Qualtrics survey platform. Dr. Bendixen granted permission to use the EBI via email (Appendix C).

Epistemically-Related Emotion Scales

The Epistemically-Related Emotion Scales (EES) is an instrument developed by Pekrun et al. (2017). The EES was designed to measure multiple epistemic emotions during learning and problem-solving and is built on a seven-factor model evaluates surprise, curiosity, enjoyment, confusion, anxiety, frustration, and boredom. This instrument was originally developed by Pekrun and Meier (2011) as the Epistemic Emotion Scales. However, it was revised and tested for validity using data from a multinational study, and was used in the development of the cognitive incongruity model (Muis et al., 2015). The EES was also used by Rosman and Mayer (2018).

Each question in the EES asks the participant how strongly they feel a particular emotion using a five-point Likert scale ranging from 1 (not at all) to 5 (very strong). This instrument includes two versions. The long version includes a total of 21 questions, three for each emotion measured. The questions utilize synonyms based around frequently used emotion words. The short version includes only seven questions, one for each emotion measured using only the primary terms. For example, the long version asks has participants rate their intensity of their boredom, dullness, and monotony. The short version has them only rate the intensity of their boredom (Pekrun et al., 2017). Validity and reliability for the EES were established in a multinational study with $N = 438$ university students. Internal validity was tested using correlational analysis and confirmatory factor analysis. Positive emotions were shown to correlate positively with one another, as were negative emotions. Positive and negative emotions correlated negatively with one another. These results suggest convergent validity. Reliabilities for all subscales were measured by Cronbach's alpha as follows: surprise ($\alpha = .84$), curiosity ($\alpha = .88$), enjoyment ($\alpha = .78$), confusion ($\alpha = .78$), anxiety ($\alpha = .76$), frustration ($\alpha = .77$), and boredom ($\alpha = .86$). The long and short versions of the EES were determined to be sufficiently similar, with averaged correlation values ranging from $r = .65$ to $r = .83$ (Pekrun et al., 2017).

The long version of the EES takes approximately 20 minutes to complete, while the short version takes approximately 5 minutes. Due to the shorter time investment and its more focused nature, the short version was utilized for this study. Furthermore, the results were grouped so as to give each participant a score on positive emotions and negative emotions. Positive emotions include surprise, curiosity, and enjoyment. Possible scores range from 3 to 15. Negative emotions included confusion, anxiety, frustration, and boredom. Possible scores for negative emotions range from 4 to 20. This instrument was administered as part of this study via Qualtrics survey platform. Dr. Pekrun granted permission to use the EES via email (Appendix C).

Attitudes about GMFs Survey

The Attitudes about GMFs Survey is an instrument developed by Heddy et al. (2017) to measure attitudes towards GMFs. This instrument was modified from Poortinga and Pidgeon's (2006) study of attitudes towards genetically modified food. This survey measures four different attitude aspects for valence, or direction, regarding GMFs: general attitude, acceptability, behavioral intentions, and concern (Heddy et al., 2017).

This short instrument uses four questions, one to assess each of the four attitude aspects.

Each question uses a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). As such, the total scores range from 1 to 20, with higher scores indicating more positive attitudes towards GMFs overall. The reliability of this measure was established with Cronbach's alpha values of .84 (Heddy et al., 2017), 0.91 (Thacker et al., 2020), and 0.93 (Muis et al., 2020). For the current study, the instrument demonstrated a cumulative Cronbach's alpha of .86.

The Attitude about GMFs Survey takes approximately 5 minutes to complete. This instrument was administered as part of this study via Qualtrics survey platform. Dr. Heddy granted permission to use this instrument via email (Appendix C).

Procedures

First, the Institutional Review Board (IRB) of the university was contacted to obtain permission to conduct the study. See Appendix A for the IRB approval letter. Then, the office of Analytics and Decision Support sent out the recruitment email to eligible participants enrolled in introductory science courses. The email introduced the study and its relevance and requested participation from them. Students were also made aware that, as an added incentive, participants were entered into a drawing to win one of three $50 Amazon gift cards. Finally, the email included a link to Qualtrics, a versatile online survey platform that is officially authorized by the university. The Qualtrics survey began with a consent form, in accordance with the IRB approval process.

Data was collected through Qualtrics in five steps, which must be completed in order. First, participants filled out the demographic questionnaire, which includes questions about gender, age, class, grade level, major, ethnicity, and religious affiliation. This step takes approximately two minutes to complete. Next, participants completed the Epistemic Belief Inventory (EBI) (Schraw et al., 2002). This instrument contains 28 questions and takes approximately 20 minutes to complete. Next, participants read a refutation text which concisely addresses several common misconceptions about GMFs, followed by a persuasive text highlighting the advantages of GMFs (Thacker et al., 2020). These texts take approximately 10 minutes to read (see Appendix B). After reading these texts, participants completed the short version of the Epistemically-Related Emotion Scales (EES) (Pekrun et al., 2017). This instrument includes seven questions and takes approximately 5 minutes to complete. Finally, participants completed the Attitudes about GMFs Survey (Heddy et al., 2017). This instrument includes four questions and takes approximately 3 minutes to complete. The entire procedure takes approximately 40 minutes to complete.

After the data were collected, they were downloaded from Qualtrics and organized into an Excel spreadsheet. Three participants were randomly selected to win the $50 Amazon gift cards, which were distributed via email. The data were stored in an Excel spreadsheet on a password-protected laptop, which is backed up to Microsoft OneDrive. Data were then analyzed using SPSS statistical software.

Data Analysis

Each of the five null hypotheses was tested using bivariate regression. This technique was used for this study because it measures the magnitude of the relationship between predictor and criterion variables, which allows the researcher to evaluate the predictive relationships of the null hypotheses. Bivariate regression is based on the assumption that the relationship between the variables is linear (Gall et al., 2007). However, before this relationship can be addressed, descriptive statistics of each variable were calculated. Then, the data set were screened for missing data and inspected for inconsistencies.

In order for bivariate linear regression to be considered an appropriate statistical methodology for determining the relationships outlined in the hypotheses, three assumptions must be met. First, the assumption of bivariate outliers must be met. This was determined by examining the scatter plots of each pair of predictor and criterion variables in question. If no extreme outliers are found, the assumption of bivariate outliers is considered tenable. Second, the assumption of linearity must be satisfied. This is determined by adding a line of fit to each scatter plot. If the data broadly follow the linear distribution corresponding with the line of fit, the assumption of linearity is considered tenable. Next, the assumption of bivariate normal distribution must be met. This is measured by inspecting the distribution and looking for the characteristic "cigar shape" around the line of fit. If this distribution is observed, the assumption of bivariate normal distribution is considered tenable (Warner, 2013).

Bivariate linear regression tests were then carried out for each of the hypotheses. For each hypothesis, *R* was calculated, which serves as the effect size statistic. Bivariate linear regression works on looking for a signal-to-noise ratio, which allows the researcher to determine how much of the criterion variables can be predicted by the predictor variable. R^2 is the metric used to determine this ratio. Furthermore, directionality of the relationship can be determined by the positive or negative value of *R*. A positive value for *R* indicates a positive correlation between the variables in question. In a bivariate linear regression, null hypothesis testing is accomplished using an *F* ratio (Warner, 2013). This value also serves to test the significance. In this study, the alpha level for each hypothesis test was set at .02 ($p = .02$). Because five regressions are being run on the same data, a Bonferroni correction was used to reduce the risk of a Type I error (Warner, 2013). Using this procedure, each of the five hypotheses was tested.

CHAPTER FOUR: FINDINGS

Overview

This chapter summarizes the results of data and its analysis. First, the research questions and hypotheses are restated. Then, the descriptive statistics for each research instrument are presented, including the mean and standard deviation for the scores assigned to these responses. Next, the assumption tests are described and found to be tenable. Each of the five null hypotheses was tested using linear bivariate regression, and the results are presented and evaluated for each null hypothesis below.

Research Questions

RQ1: Do *epistemic beliefs* of undergraduate students predict *epistemic emotions* following refutation of common misconceptions about GMFs?

RQ2: Do *epistemic beliefs* of undergraduate students predict *attitudes towards GMFs* following refutation of common misconceptions?

RQ3: Do *epistemic emotions* of undergraduate students predict *attitudes towards GMFs* following refutation of common misconceptions?

Hypotheses

The null hypotheses for this study are:

$H_0$1: There is no statistically significant predictive relationship between the predictor variable, *epistemic beliefs* of undergraduate students, as measured by the Epistemic Belief Inventory, and the criterion variable, *positive epistemic emotions*, as measured by the Epistemically-Related Emotion Scales following refutation of common misconceptions about GMFs.

$H_0$2: There is no statistically significant predictive relationship between the predictor variable, *epistemic beliefs* of undergraduate students, as measured by the Epistemic Belief Inventory, and the criterion variable, *negative epistemic emotions*, as measured by the Epistemically-Related Emotion Scales following refutation of common misconceptions about GMFs.

$H_0$3: There is no statistically significant predictive relationship between the predictor variable, *epistemic beliefs* of undergraduate students, as measured by the Epistemic Belief Inventory, and the criterion variable, *attitudes towards GMFs*, as measured by the Attitudes about GMFs survey following refutation of common misconceptions about GMFs.

$H_0$4: There is no statistically significant predictive relationship between the predictor variable, *positive epistemic emotions* of undergraduate students, as measured by the Epistemically-Related Emotion Scales, and the criterion variable, *attitudes towards GMFs*, as measured by the Attitudes about GMFs survey following refutation of common misconceptions about GMFs.

$H_0$5: There is no statistically significant predictive relationship between the predictor variable, *negative epistemic emotions* of undergraduate students, as measured by the Epistemically-Related Emotion Scales, and the criterion variable, *attitudes towards GMFs*, as measured by the Attitudes about GMFs survey following refutation of common misconceptions about GMFs.

Descriptive Statistics

Data for this study were collected using a series of survey instruments. Epistemic beliefs were evaluated using Schraw et al.'s (2002) Epistemic Beliefs Inventory (EBI). Epistemic emotions were assessed using Pekrun et al.'s (2017) Epistemically-Related Emotion Scales

(EES), which was divided into separate assessments for positive and negative emotions. Finally, participants' attitudes towards GMFs were evaluated using Heddy et al.'s (2017) Attitudes towards GMFs survey. The survey response percentages for each survey are included in Appendix D. Each instrument yields a score for each participant based on the sum of their scored responses, as described in the preceding Instrumentation section. Descriptive statistics for these scores are included in Table 1.

Table 1

Descriptive Statistics for Instrument Scores

Instrument	Minimum	Maximum	*M*	SD	*N*
EBI	55	104	79.69	9.345	78
EES (Positive)	4	13	8.49	1.688	78
EES (Negative)	4	18	9.76	3.212	78
Attitudes about GMFs	4	20	12.88	3.117	78

Results

Assumption Tests

Each of the five hypothesis was tested using bivariate linear regression, which requires that three assumptions first be met. First, the assumption of bivariate outliers was tested by examining the scatter plot for each pair of predictor and criterion variables. No extreme outliers were found, so the assumption of bivariate outliers was found to be tenable. Second, a line of fit was added to each scatter plot to test assumption of linearity. Since the data broadly followed the linear distribution, the assumption of linearity was considered tenable. Finally, the scatter plots were examined to test the assumption of bivariate normal distribution. The characteristic "cigar shape" around the line of fit was found, indicating this assumption was considered tenable.

Hypotheses

The first null hypothesis is as follows:

$H_0$1: There is no statistically significant predictive relationship between the predictor variable, *epistemic beliefs* of undergraduate students, as measured by the Epistemic Belief Inventory, and the criterion variable, *positive epistemic emotions*, as measured by the Epistemically-Related Emotion Scales following refutation of common misconceptions about GMFs. Results did not indicate a significant predictive relationship between the predictor variable (EBI Score) and the criterion variable (EES Positive Score). Thus, the null hypothesis was not rejected at a 98% confidence interval: $F(1, 76) = .178$, $p = .674$. See Figure 1 for the scatter plot, Table 2 for the results of the ANOVA, and Table 3 for the results of the model analysis.

Figure 1

Scatter Plot of Criterion and Predictor Variables for $H_0$1

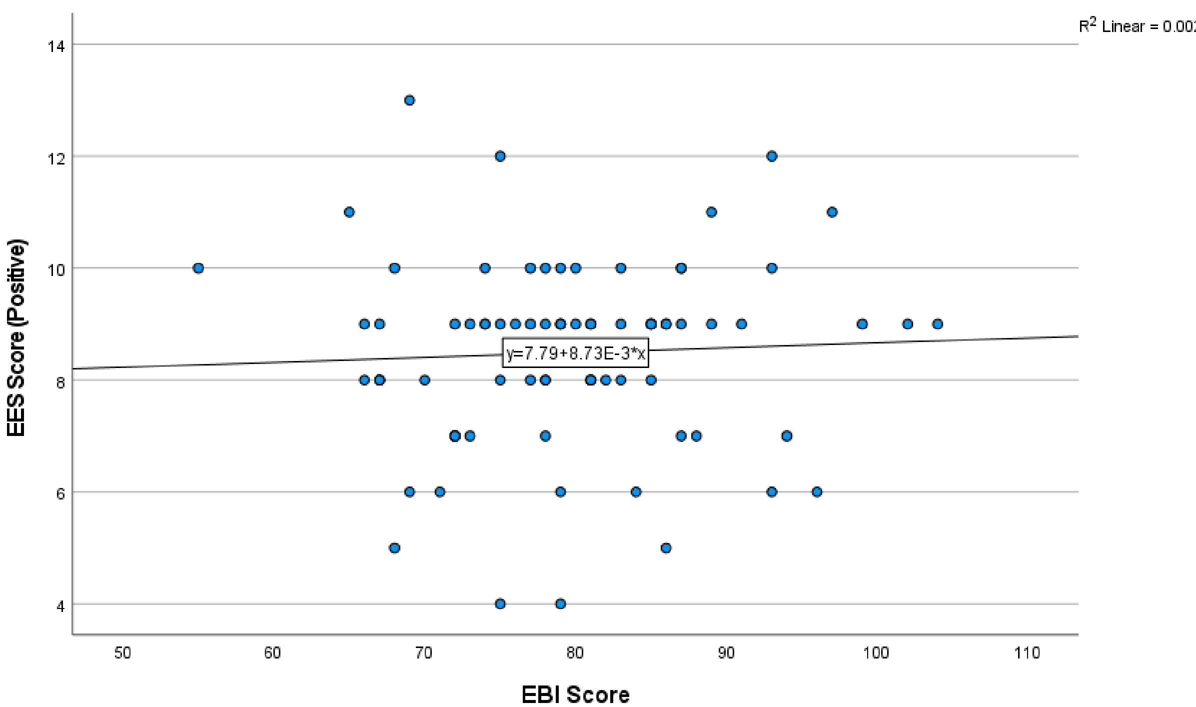

Table 2

ANOVA Results for H_01

Source	Sum of Squares	*df*	Mean Square	*F*	Sig.
Regression	.512	1	.512	.178	.674
Residual	218.975	76	2.881		
Total	219.487	77			

Table 3

Model Summary for H_01

R	R Square	Adjusted R Square	Std. Error of the Estimate
.048	.002	-.011	1.697

The second null hypothesis is as follows:

H_02: There is no statistically significant predictive relationship between the predictor variable, *epistemic beliefs* of undergraduate students, as measured by the Epistemic Belief Inventory, and the criterion variable, *negative epistemic emotions*, as measured by the Epistemically-Related Emotion Scales following refutation of common misconceptions about GMFs. Results did not indicate a significant predictive relationship between the predictor variable (EBI Score) and the criterion variable (EES Negative Score). Thus, the null hypothesis was not rejected at a 98% confidence interval: $F(1, 76) = 5.167$, $p = .026$. See Figure 2 for the scatter plot, Table 4 for the results of the ANOVA, and Table 5 for the results of the model analysis.

Figure 2

Scatter Plot of Criterion and Predictor Variables for $H_0 2$

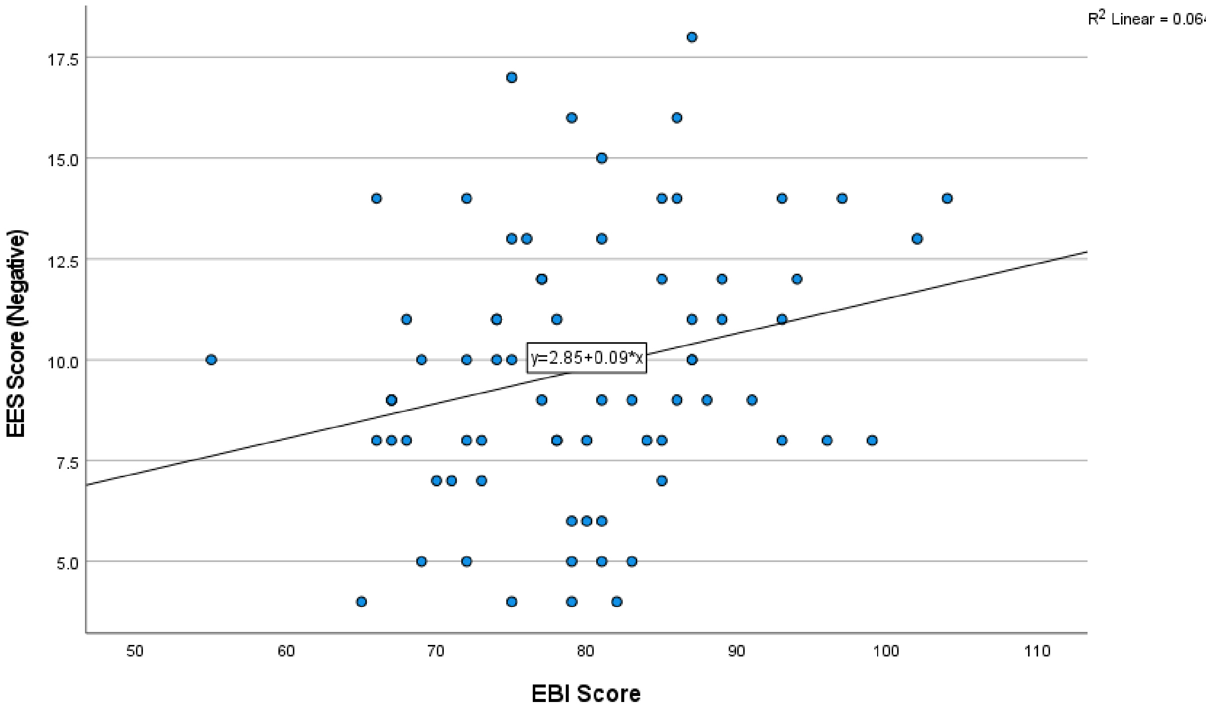

Table 4

ANOVA Results for $H_0 2$

Source	Sum of Squares	*df*	Mean Square	*F*	Sig.
Regression	50.571	1	50.571	5.167	.026
Residual	743.801	76	9.787		
Total	794.372	77			

Table 5

Model Summary for $H_0 2$

R	R Square	Adjusted R Square	Std. Error of the Estimate
.252	.064	.051	3.128

The third null hypothesis is as follows:

H₀3: There is no statistically significant predictive relationship between the predictor variable, *epistemic beliefs* of undergraduate students, as measured by the Epistemic Belief Inventory, and the criterion variable, *attitudes towards GMFs*, as measured by the Attitudes about GMFs survey following refutation of common misconceptions about GMFs. Results did not indicate a significant predictive relationship between the predictor variable (EBI Score) and the criterion variable (Attitudes towards GMFs Score). Thus, the null hypothesis was not rejected at a 98% confidence interval: $F(1, 76) = .373$, $p = .543$. See Figure 3 for the scatter plot, Table 6 for the results of the ANOVA, and Table 7 for the results of the model analysis.

Figure 3

Scatter Plot of Criterion and Predictor Variables for $H_0 3$

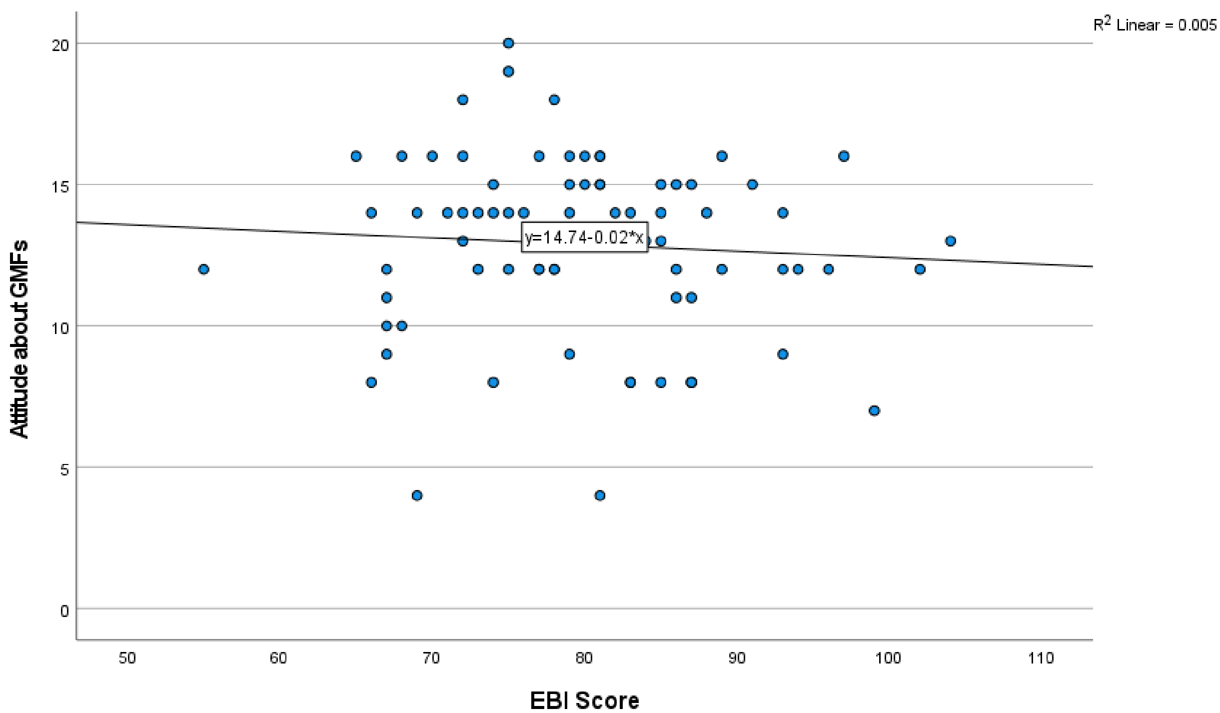

Table 6

ANOVA Results for $H_0$3

Source	Sum of Squares	*df*	Mean Square	*F*	Sig.
Regression	3.655	1	3.655	.373	.543
Residual	744.307	76	9.794		
Total	747.962	77			

Table 7

Model Summary for $H_0$3

R	R Square	Adjusted R Square	Std. Error of the Estimate
.070	.005	-.008	3.129

The fourth null hypothesis is as follows:

$H_0$4: The fourth null hypothesis is as follows: There is no statistically significant predictive relationship between the predictor variable, *positive epistemic emotions* of undergraduate students, as measured by the Epistemically-Related Emotion Scales, and the criterion variable, *attitudes towards GMFs*, as measured by the Attitudes about GMFs survey following refutation of common misconceptions about GMFs. Results did not indicate a significant predictive relationship between the predictor variable (EES Positive Score) and the criterion variable (Attitudes towards GMFs Score). Thus, the null hypothesis was not rejected at a 98% confidence interval: $F(1, 76) = 3.818$, $p = .054$. See Figure 4 for the scatter plot, Table 8 for the results of the ANOVA, and Table 9 for the results of the model analysis.

Figure 4

Scatter Plot of Criterion and Predictor Variables for H₀4

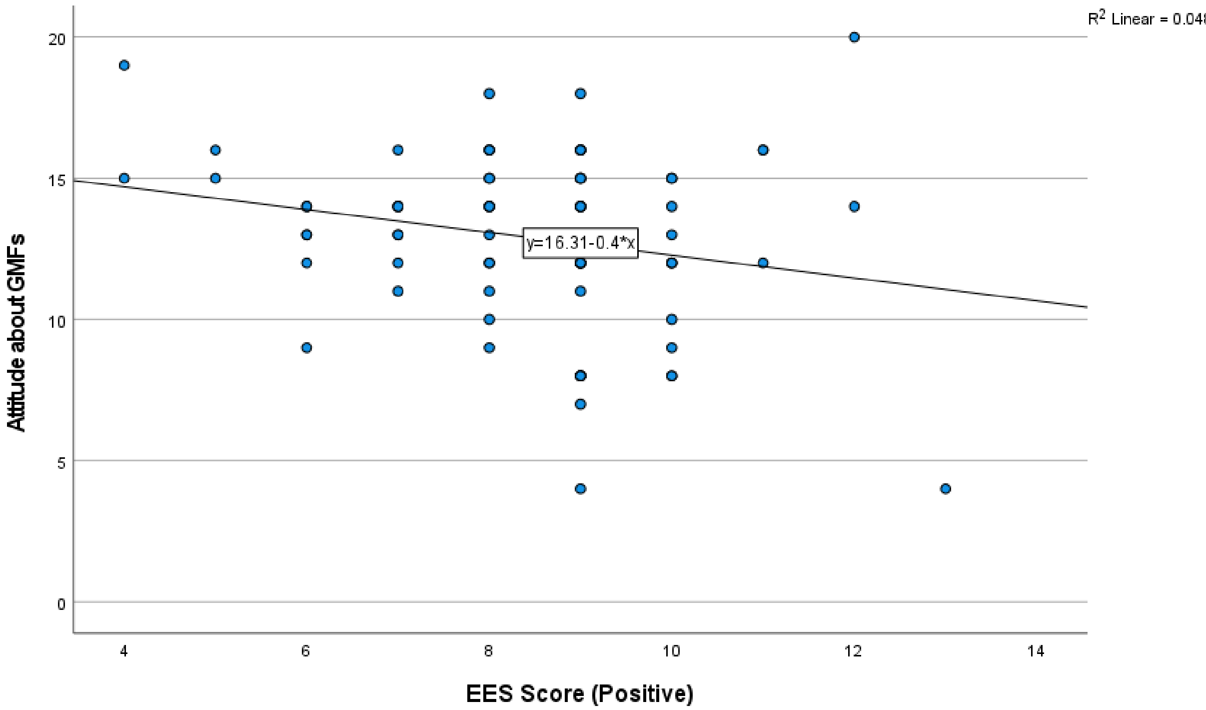

Table 8

ANOVA Results for $H_0 4$

Source	Sum of Squares	*df*	Mean Square	*F*	Sig.
Regression	35.777	1	35.777	3.818	.054
Residual	712.184	76	9.371		
Total	747.962	77			

Table 9

Model Summary for $H_0 4$

R	R Square	Adjusted R Square	Std. Error of the Estimate
.219	.048	.035	3.061

The fifth null hypothesis is as follows:

H_05: There is no statistically significant predictive relationship between the predictor variable, *negative epistemic emotions* of undergraduate students, as measured by the Epistemically-Related Emotion Scales, and the criterion variable, *attitudes towards GMFs*, as measured by the Attitudes about GMFs survey following refutation of common misconceptions about GMFs. Results indicated a significant predictive relationship between the predictor variable (EES Negative Score) and the criterion variable (Attitudes towards GMFs Score). Thus, the null hypothesis was rejected at a 98% confidence interval: $F(1, 76) = 7.875$, $p = .006$. The regression analysis yielded an R-value of .306, indicated a medium effect size. See Figure 5 for the scatter plot, Table 10 for the results of the ANOVA, and Table 11 for the results of the model analysis.

Figure 5

Scatter Plot of Criterion and Predictor Variables for H_05

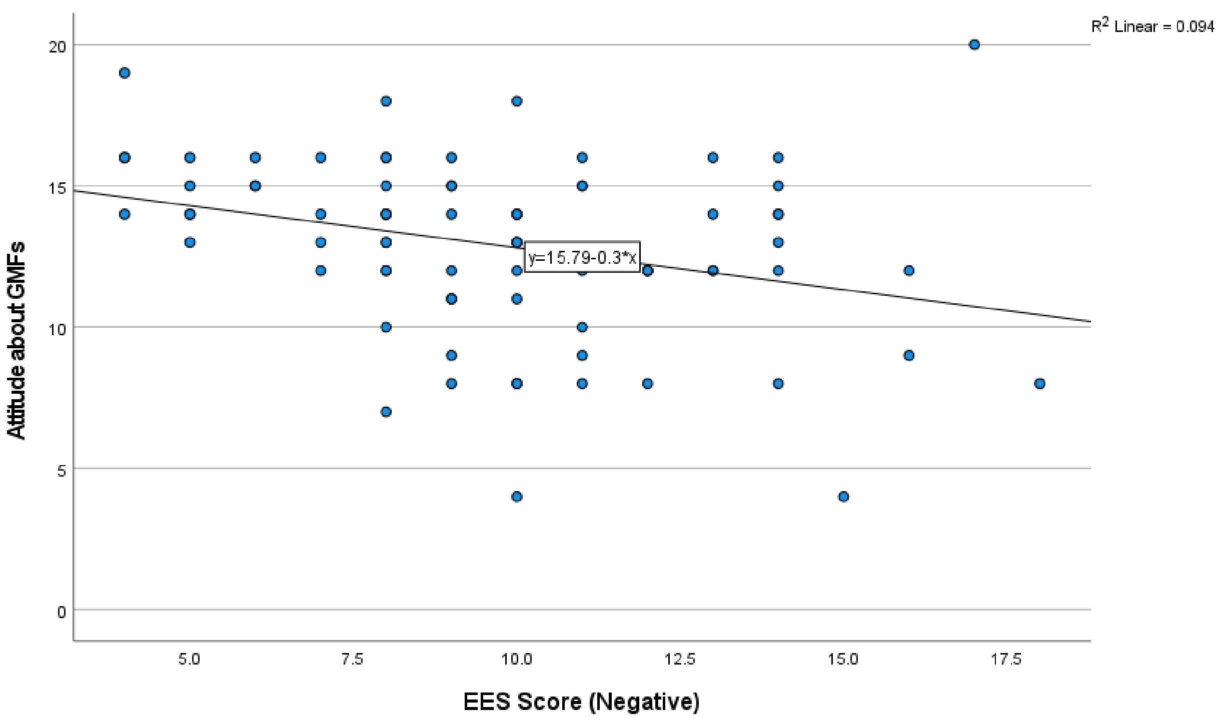

Table 10

ANOVA Results for $H_0$5

Source	Sum of Squares	*df*	Mean Square	*F*	Sig.
Regression	70.228	1	70.228	7.875	.006
Residual	677.734	76	8.918		
Total	747.962	77			

Table 11

Model Summary for $H_0$5

R	R Square	Adjusted R Square	Std. Error of the Estimate
.306	.094	.082	2.986

CHAPTER FIVE: CONCLUSIONS

Overview

This chapter will discuss the findings of this study, including their implications, limitations, and recommendations for future research. It will begin with an analysis of the results for each research question in light of the relevant literature. Next, the research and practical implications of the study will be discussed. Lastly, the studies limitations will be addressed, along with considerations for future research.

Discussion

The purpose of this study is to examine the relationship between epistemic beliefs, epistemic emotions, and attitudes towards GMFs among undergraduate students. This was accomplished by addressing three research questions. The first question addressed the effects of epistemic belief on epistemic emotions, both positive and negative. The second explored the effects of epistemic beliefs on attitudes towards GMFs. The third examined the relationship between epistemic emotions, both positive and negative, on attitudes towards GMFs. These three questions generated five hypotheses. Each hypothesis was tested through the use of bivariate linear regression to determine if a predictive relationship existed.

Research Question 1

Epistemic beliefs, as measured using the Epistemic Beliefs Inventory (EBI), were compared to epistemic emotions, as measured using the Epistemically-Related Emotion Scales (EES). Two null hypotheses were used in order to evaluate positive emotions (surprise, curiosity, and enjoyment) as well as negative emotions (confusion, anxiety, frustration, and boredom). The results of the bivariate regression analyses indicated no predictive relationship between EBI score and positive or negative EES scores, failing to reject the null hypotheses.

The theoretical basis for the interplay between epistemic beliefs and emotions is well established (Bendixen & Rule, 2004; Muis, Chevrier et al., 2018; Pekrun, 2006). Posner et al. (1982) noted that learning information that is inconsistent with one's beliefs results in negative emotions. The effect of such beliefs on epistemic emotions has also been experimentally demonstrated (Rosman & Mayer, 2018). Multiple studies have shown that efforts to address epistemic beliefs have positively impacted epistemic emotions of students learning about climate change, and have even improved critical thinking surrounding the topic (Chevrier et al., 2019; Muis et al., 2015; Trevors et al., 2017). Similarly, more constructivist epistemic beliefs have also been correlated to more positive emotions while learning about GMFs. In particular, participants' beliefs about the complexity, source, justification, and certainty of knowledge had variable effects on their emotions when presented with a text refuting common misconception about GMFs. Participants with more constructivist beliefs were more likely to have positive emotional responses to the correction of GMF misconceptions (Muis et al., 2021). However, this relationship was not demonstrated in the current study. The results instead failed to indicate a significant correlation between epistemic beliefs and epistemic emotions, be they positive or negative.

Research Question 2

Epistemic beliefs were also compared to participants' attitudes towards GMFs. The results of the bivariate linear regression indicated no significant predictive relationship between epistemic beliefs and GMF attitudes, failing to reject the third null hypothesis.

Theoretical models of conceptual change have increasingly incorporated the factors of epistemic belief on attitude change (Nadelson et al., 2018; Sinatra & Seyranian, 2016). More mature epistemic beliefs have been experimentally correlated to SSI attitudes, namely acceptance of evolution (Borgerding et al., 2017). Trevors et al. (2016) also demonstrated the effect of individual self-concept, including epistemic beliefs, on attitudes towards GMFs. GMF misconceptions have also been correlated with increased construal-based reasoning, particularly essentialism (Potter et al., 2017). For example, Pope et al. (2017) found that Christians relied more heavily on essentialist and teleological arguments. Furthermore, epistemic beliefs have been shown to influence epistemic emotions (Muis, Chevrier et al., 2018; Muis et al., 2021), which are mediators between conceptual change and attitude change (Heddy et al., 2017; McPhetres et al., 2019). However, the results of the current study failed to demonstrate the correlation between epistemic beliefs and attitudes towards GMFs. These results are not surprising given the aforementioned lack of correlation between epistemic beliefs and emotions, which typically mediate attitudes towards such topics.

Research Question 3

The final research question concerned the effect of epistemic emotions on attitudes towards GMFs. Two null hypotheses were used: one for positive emotions and one for negative emotions. The results indicated no predictive relationship between positive emotions and attitudes towards GMFs. However, negative emotions were found to have a significant correlation with more negative attitudes towards GMFs. Therefore, the results failed to reject the fourth null hypothesis, but rejected the fifth.

Several studies have explored the impact of emotions on attitudes towards GMFs, primarily in the context of conceptual and attitude change. While the current study did not assess changes in attitude, several points of comparison still exist. Petty and Briñol (2015) theorized that emotions act as mediators between conceptual and attitude change. This relationship was later demonstrated in several studies that assessed college students' emotions and attitudes towards GMFs following the correction of misconceptions (Chrispeels et al., 2019; Heddy et al., 2017; Muis et al., 2020; Thacker et al., 2020).

Prior research has shown that prior general knowledge does not predict positive attitudes towards GMFs, knowledge of biology and biotechnology does predict such attitudes (Allum et al., 2008; McPhetres et al., 2019). Similarly, the current study found moderate attitudes among non-biology majors, with a mean score of 12.88 on the Attitudes towards GMFs survey. However, positive emotions were not found to be correlated to positive attitudes. In contrast, prior studies have found that GMF attitude change correlated more strongly with positive emotions than negative emotions (Heddy et al., 2017; Thacker et al., 2020). Though again, the current study is only measuring change after exposure to a refutation text without a prior measurement for comparison.

The findings of the current study indicated a statistically significant, negative relationship between EES negative scores and scores on the Attitudes towards GMFs survey. The regression analysis indicated a medium effect size. Because lower scores for the latter survey indicate more negative attitudes, these findings demonstrate a direct correlation between negative emotions and negative attitudes. These findings are consistent with the general pattern of emotional and attitude change in other studies (Heddy et al., 2017; Muis et al., 2020). However, this correlation was found after participants read a text refuting common GMF misconceptions a persuasive text arguing for their use. The current study cannot evaluate whether their attitudes changed as a result of this experience, but the prevalence of negative emotions following these texts warrants further consideration. The strongest negative attitudes towards GMFs have been correlated with weak GMF knowledge and strong confidence, which is reminiscent of the Dunning-Kruger effect (Fernbach et al., 2019). According to this effect, people often overestimate their own understanding of unfamiliar topics, resulting in disproportionate confidence and erroneous conclusions (Kruger & Dunning, 1999). To this end, some studies have successfully demonstrated increases in positive attitudes through extended educational efforts (Chrispeels et al., 2019; McPhetres et al., 2019). However, another possibility is that participants' attitudes became more polarized in response to the refutation and persuasive texts. The backfire effect, which occurs when attempts to correct misconceptions instead result in increased commitment, have been documented in multiple SSIs, including GMFs (Lewandowsky et al., 2012). Dinsmore et al. (2017) found that some participants actually adopted less complex viewpoints when presented with a persuasive texts attempting to correct GMF misconceptions. Similarly, Trevors et al. (2016) proposed that some people's self-concepts can become threatened by refutation of prior conceptions about GMFs, resulting in a defensive response to the information. This reaction then leads to negative emotions and attitudes and can impair learning. Thus, emotions may push attitudes further to their valence, be it positive or negative (Muis et al., 2020).

Among the negative emotions that correlated with negative attitudes towards GMFs was confusion. Confusion is one of the most common epistemic emotions encountered by students, and is typically unpleasant. Confusion is a natural response to the disequilibrium caused by discrepancies between prior conceptions and new information (D'Mello & Graesser, 2012). Left unresolved, confusion results in frustration. However, if confusion is resolved, it can lead to positive emotions and improved learning (D'Mello et al., 2014; Muis, Chevrier et al., 2018). This was demonstrated by Muis et al. (2021), who found that confusion and anxiety actually predicted higher critical thinking regarding GMFs. Thus, in the long run, such negative emotions may lead to more careful consideration of GMFs.

Implications

This study sought to address the gap in the research literature of the effects of epistemic beliefs and emotions on attitudes towards GMFs. The findings did not demonstrate significant correlations between epistemic beliefs and emotions that had been shown in previous studies (Chevrier et al., 2019; Muis et al., 2021; Trevors et al., 2016). They also did not demonstrate a relationship between epistemic beliefs and attitudes towards GMFs. However, the findings demonstrated a significant predictive correlation between negative epistemic emotions and attitudes towards GMFs. These results were consistent with previous findings that a relationship existed, and added further clarity to the nature of this relationship (Heddy et al., 2017; Muis et al., 2020; Thacker et al., 2020).

Furthermore, the scholarly implications of this study extend to ongoing considerations of science literacy in society. Adherents of the deficit model propose that attitudes towards SSI are primarily shaped by access to information (Simis et al., 2016). Thus, opposing attitudes towards GMFs can be remedied by correcting misconceptions. However, the findings of this study further emphasize the role of epistemic emotions in the process of conceptual change. Participants read a refutation text designed to correct GMF misconceptions, as well as a text that persuasively argued for the benefits of genetic engineering technology in the food system. Then, they reported negative epistemic emotions that directly correlated with negative attitudes towards GMFs. These results support the previous findings that epistemic emotions are a significant factor in predicting attitudes towards GMFs.

Educational research is not merely scholarly in nature but is also intended to inform practice. Therefore, these findings bear practical classroom implications for science educators. The use of SSIs allows students to apply scientific concepts to pressing societal issues, including

GMFs. However, lack of consideration for epistemic factors may result in reduced efficacy. Efforts should be made to discuss these topics in a winsome and positive fashion. If students are able to experience less frustration, anxiety, and boredom while learning about GMFs, they are less likely to develop negative attitudes. If confusion is used as a learning opportunity, it is less likely to grow into frustration and more likely to yield positive emotions (D'Mello et al., 2014; Muis, Chevrier et al., 2018). Furthermore, positive emotions also predict more effective learning strategies (Chevrier et al., 2019; Muis et al., 2015).

Limitations

Despite the relevance of these findings to both research and practice, generalizability is limited by number of factors. While the sample size (*N* = 78) was large enough to exceed the requirements for a medium effect size (*N* = 66), a larger sample would improve clarity of the results (Gall et al., 2007). Participants were drawn from a convenience sample of students in eight classes at one university. Moreover, the majority of participants (96%) were of Christian affiliation, which may have impacted epistemic beliefs and prevalence of construal-based reasoning (Pope et al., 2017).

Additionally, the selection criteria for this study required that participants be from non-biology majors who had not taken a college-level biology course. This was meant to reduce the possibility that they had formed educated attitudes towards GMFs. However, it may also have resulted in a lower value placed on the topic, which is a key factor influencing emotional response (Pekrun, 2006). Decreased value may also result in decreased elaboration, which can influence attitude change (Petty & Briñol, 2015). Lower value may decreased cognitive processing, resulting in more emotional consideration of perceived risk (Loewenstein et al., 2001).

In this study, epistemic emotions were clustered into positive (surprise, curiosity, enjoyment) and negative (confusion, anxiety, frustration, boredom). While the findings indicated a predictive relationship between negative emotion and negative attitudes towards GMFs, the analysis cannot distinguish which emotions were specifically correlated. Furthermore, at times, confusion has been shown to have positive epistemic effects, which cannot be distinguished in the present study (D'Mello et al., 2014).

Finally, these findings cannot measure change in conceptions, epistemic emotions, or attitudes towards GMFs through the course of the study. The variables were each measured once, which indicated a correlation between negative emotions and negative attitudes. However, this leaves many unanswered questions concerning the interplay of epistemic beliefs and emotions during conceptual and emotional change.

Recommendations for Future Research

Future research into this topic should seek to address the above limitations in generalizability. A larger sample drawn from multiple universities would provide greater clarity into the variables being measured. Further, a more diverse sampling of religious worldviews may further illuminate the relationships between epistemic beliefs, emotions, and attitudes towards GMFs.

Later studies should also incorporate biology majors, whose assessment of value may be higher than non-majors. Previous research has shown that higher value is correlated to greater surprise in response to GMF refutation texts (Muis, Sinatra et al., 2018). This may help clarify the relationship between positive emotions and attitudes towards GMFs.

In contrast to the present study, future research should seek to explore the role of separate emotions. This could further clarify one outcome of the present study. A slight association was observed between epistemic beliefs and negative epistemic emotions. The second null hypothesis was rejected because this correlation did not meet the threshold for statistical significance. However, further study into separate emotions may find a significant predictive relationship.

Additionally, further research could explore the relationship between epistemic beliefs and emotions in the context of conceptual and attitude change. The present study was limited to a single assessment of each variable, with no assessment of participants' misconceptions about GMFs. Addressing the role of beliefs and emotions during conceptual and attitude change would allow for more direct comparison with other findings (Heddy et al., 2017; McPhetres et al., 2019). Additional research to consider includes:

1. Exploring the influence of Christian worldview on epistemic beliefs and attitudes towards GMFs.
2. Comparing epistemic beliefs and emotions between biology majors and non-majors.
3. Exploring the role of confusion on GMF attitudes in low-elaboration and high-elaboration settings.
4. The impact of activating and deactivating epistemic emotions on conceptual and attitude change regarding GMFs.

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APPENDIX A: IRB Approval Letter

LIBERTY UNIVERSITY
INSTITUTIONAL REVIEW BOARD

October 4, 2021

David Lee
Jillian Wendt

Re: IRB Exemption - IRB-FY21-22-79 THE EFFECTS OF EPISTEMIC BELIEFS ON STUDENTS' EMOTIONS AND ATTITUDES TOWARDS GENETICALLY MODIFIED FOODS

Dear David Lee, Jillian Wendt,

The Liberty University Institutional Review Board (IRB) has reviewed your application in accordance with the Office for Human Research Protections (OHRP) and Food and Drug Administration (FDA) regulations and finds your study to be exempt from further IRB review. This means you may begin your research with the data safeguarding methods mentioned in your approved application, and no further IRB oversight is required.

Your study falls under the following exemption category, which identifies specific situations in which human participants research is exempt from the policy set forth in 45 CFR 46:104(d):

Category 2.(i). Research that only includes interactions involving educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior (including visual or auditory recording).
The information obtained is recorded by the investigator in such a manner that the identity of the human subjects cannot readily be ascertained, directly or through identifiers linked to the subjects.

Your stamped consent form(s) and final versions of your study documents can be found under the Attachments tab within the Submission Details section of your study on Cayuse IRB. Your stamped consent form(s) should be copied and used to gain the consent of your research participants. If you plan to provide your consent information electronically, the contents of the attached consent document(s) should be made available without alteration.

Please note that this exemption only applies to your current research application, and any modifications to your protocol must be reported to the Liberty University IRB for verification of continued exemption status. You may report these changes by completing a modification submission through your Cayuse IRB account.

If you have any questions about this exemption or need assistance in determining whether possible modifications to your protocol would change your exemption status, please email us at irb@liberty.edu.

Sincerely,
G. Michele Baker, MA, CIP
Administrative Chair of Institutional Research
Research Ethics Office

LIBERTY UNIVERSITY
INSTITUTIONAL REVIEW BOARD

November 16, 2021

David Lee
Jillian Wendt

Re: Modification - IRB-FY21-22-79 THE EFFECTS OF EPISTEMIC BELIEFS ON STUDENTS' EMOTIONS AND ATTITUDES TOWARDS GENETICALLY MODIFIED FOODS

Dear David Lee, Jillian Wendt:

The Liberty University Institutional Review Board (IRB) has rendered the decision below for IRB-FY21-22-79 THE EFFECTS OF EPISTEMIC BELIEFS ON STUDENTS' EMOTIONS AND ATTITUDES TOWARDS GENETICALLY MODIFIED FOODS.

Decision: Exempt

Your request to "include 4 new introductory science courses for sampling: BIOL102, CHEM105, CHEM107, and CHEM121" has been approved. Thank you for submitting your revised study documents for our review and documentation. Your revised, stamped consent form and final versions of your study documents can be found under the Attachments tab within the Submission Details section of your study in Cayuse IRB. Your stamped consent form should be copied and used to gain the consent of your research participants. If you plan to provide your consent information electronically, the contents of the attached consent document should be made available without alteration.

Thank you for complying with the IRB's requirements for making changes to your approved study. Please do not hesitate to contact us with any questions.

We wish you well as you continue with your research.

Sincerely,

G. Michele Baker, MA, CIP
Administrative Chair of Institutional Research
Research Ethics Office

APPENDIX B: Refutation & Persuasive Texts

The following refutation text addresses common misconceptions about GMFs (Thacker et al., 2020):

This text was removed due to copyright.

APPENDIX C: Permission to Use Instruments

Permission to use Epistemic Beliefs Inventory (EBI)

From: David A. Lee
Sent: Tuesday, June 1, 2021 10:53 AM
To: Lisa Bendixen
Subject: Permission to use Schraw's Epistemic Beliefs Inventory

Good afternoon Dr. Bendixen,

My name is David Lee. I am a doctoral candidate at Liberty University, pursuing a Ph.D. in Education with an emphasis in Curriculum and Instruction. My dissertation, which is currently in the proposal phase, will focus on the effect of epistemic beliefs on students' emotions and attitudes towards GMOs. The purpose of this email is to request permission to use Schraw's Epistemic Beliefs Inventory.

Thank you for your consideration.

David A. Lee

From: Lisa Bendixen
Sent: Thursday, June 3, 2021 5:37 PM
To: David A. Lee
Subject: Re: Permission to use Epistemically-Related Emotion Scales (EES)

Hi David,

You have my permission to use the EBI. If you have any questions feel free to contact me and best wishes on your research!

Best,
Lisa

Permission to use Epistemically-Related Emotion Scales (EES)

From: David A. Lee
Sent: Friday, July 2, 2021 8:15 AM
To: Reinhard Pekrun
Subject: Permission to use Epistemically-Related Emotion Scales (EES)

Good day Dr. Pekrun,

My name is David Lee. I am a doctoral candidate at Liberty University, pursuing a Ph.D. in Education with an emphasis in Curriculum and Instruction. My dissertation, which is currently in the proposal phase, will focus on the effect of epistemic beliefs on students' emotions and attitudes towards GMOs. The purpose of this email is to request permission to use the short version of the Epistemically-Related Emotion Scales.

Thank you for your consideration.

David A. Lee

From: Reinhard Pekrun
Sent: Friday, July 2, 2021 3:16 PM
To: David A. Lee
Subject: Re: Permission to use Epistemically-Related Emotion Scales (EES)

Dear David,

thank you for your interest in the EES. Please feel free to use the instrument for your research.

Best wishes for your work,

Reinhard Pekrun

Permission to use the Attitudes about GMFs Survey

From: David A. Lee
Sent: Tuesday, June 1, 2021 1:57 PM
To: Benjamin C. Heddy
Subject: Permission to use the Attitudes about GMFs Survey

Good afternoon Dr. Heddy,

My name is David Lee. I am a doctoral candidate at Liberty University, pursuing a Ph.D. in Education with an emphasis in Curriculum and Instruction. My dissertation, which is currently in the proposal phase, will focus on the effect of epistemic beliefs on students' emotions and attitudes towards GMOs. The purpose of this email is to request permission to use the Attitudes about GMFs Survey.

Thank you for your consideration.

David A. Lee

From: Benjamin C. Heddy
Sent: Tuesday, June 1, 2021 2:49 PM
To: David A. Lee
Subject: Re: Permission to use Epistemically-Related Emotion Scales (EES)

Hi David,

Nice to meet you! Of course you can use the materials. Do you want me to send or do you have access to them through the manuscript?

Ben

APPENDIX D: Survey Results

Table 12

Epistemic Beliefs Inventory (EBI) Subscale Response Percentages

Question	Strongly Disagree	Disagree	Unsure	Agree	Strongly Agree
1. Most things worth knowing are easy to understand.	6.4	42.3	12.8	29.5	9.0
2. What is true is a matter of opinion.	43.6	28.2	14.1	12.8	1.3
3. Students who learn things quickly are the most successful.	9.0	59.0	14.1	14.1	3.8
4. People should always obey the law.	1.3	17.9	24.4	42.3	14.1
5. People's intellectual potential is fixed at birth.	25.6	50.0	16.7	7.7	0.0
6. Absolute moral truth does not exist.*	43.6	26.9	20.5	7.7	1.3
7. Parents should teach their children all there is to know about life.	1.3	33.3	21.8	35.9	7.7
8. Really smart students don't have to work as hard to do well in school.	10.3	42.3	10.3	32.1	5.1
9. If a person tries too hard to understand a problem, they will most likely end up being confused.	6.4	43.6	16.7	28.2	5.1
10. Too many theories just complicate things.	7.7	28.2	24.4	35.9	3.8
11. The best ideas are often the most simple.	2.6	30.8	19.2	37.2	10.3
12. Instructors should focus on facts instead of theories.	2.6	35.9	32.1	26.9	2.6
13. Some people are born with special gifts and talents.	0.0	7.7	3.8	38.5	50.0
14. How well you do in school depends on how smart you are.	24.4	52.6	11.5	11.5	0.0
15. If you don't learn something quickly, you won't ever learn it.	59.7	36.4	2.6	1.3	0.0

Epistemic Beliefs Inventory (EBI) Subscale Response Percentages (continued)

Question	Strongly Disagree	Disagree	Unsure	Agree	Strongly Agree
16. Some people just have a knack for learning and others don't.	5.1	17.9	7.7	56.4	12.8
17. Things are simpler than most professors would have you believe.	2.6	25.6	29.5	38.5	3.8
18. If two people are arguing about something, at least one of them must be wrong.	14.1	59.0	10.3	14.1	2.6
19. Children should be allowed to question their parents' authority.*	12.8	33.3	25.6	24.4	3.8
20. If you haven't understood a chapter the first time through, going back over it won't help.	42.3	51.3	3.8	2.6	0.0
21. Science is easy to understand because it contains so many facts.	24.4	44.9	17.9	11.5	1.3
22. The more you know about a topic, the more there is to know.	0.0	3.8	23.1	56.4	16.7
23. What is true today will be true tomorrow.	7.7	37.2	21.8	19.2	14.1
24. Smart people are born that way.	11.5	51.3	20.5	16.7	0.0
25. When someone in authority tells me what to do, I usually do it.	1.3	5.1	15.4	60.3	17.9
26. People shouldn't question authority.	12.8	53.8	20.5	7.7	5.1
27. Working on a problem with no quick solution is a waste of time.	37.7	51.9	5.2	3.9	1.3
28. Sometimes there are no right answers to life's big problems.	3.8	19.2	14.1	43.6	19.2

* These questions were reverse-coded.

Table 13

Epistemically-Related Emotion Scales (EES) Subscale Response Percentages

	Emotion	Not at all	Very Little	Moderate	Strong	Very Strong
Positive	Surprised	6.4	21.8	62.8	9.0	0.0
	Curious	1.3	17.9	46.2	29.5	5.1
	Excited	11.5	34.6	41.0	12.8	0.0
Negative	Confused	20.5	23.1	43.6	11.5	1.3
	Anxious	29.5	33.3	21.8	10.3	5.1
	Frustrated	38.5	26.9	24.4	7.7	2.6
	Bored	9.0	26.9	34.6	25.6	3.8

Table 14

Attitudes towards GMFs Subscale Response Percentages

Question	Not at all	Very Little	Moderate	Strong	Very Strong
1. Genetically modified foods are okay with me.	3.8	23.1	34.6	30.8	7.7
2. Genetically modified foods are beneficial to society.	2.6	16.7	30.8	46.2	3.8
3. I approve of genetically modified foods.	3.8	17.9	46.2	29.5	2.6
4. I would eat food that has been genetically modified.	3.8	17.9	28.2	42.3	7.7