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# Assessing the Scientific Literacy in Agriculture of Secondary Agricultural Education Students – An Exploratory Study

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**Abstract**

*This descriptive study explored the science literacy of secondary agricultural education students in the context of Genetically Modified Organisms (GMO). Forty-nine students from Oklahoma were asked of their opinion of GMO products and were then asked to provide a description of how genetic modification occurred. The interviews were recorded and then observed in order to determine students' dimension of scientific literacy as defined by Bybee (1997). A criterion-referenced exam was also administered to assess student's knowledge of GMOs. It was found that students had very little knowledge in both the agriculture and science of GMOs. The overwhelming majority expressed they would consume GMO products, but had an invalid, or no, theory to support that decision. These results are concerning when viewed in relation to the multitude of research indicating that agriculture, as the context for science, leads to critical thinking and depth of understanding. It was recommended that teachers of both science and agriculture focus more on the application of key concepts to develop critical thinking and scientific literacy.*

## Introduction

In his recent text, *How to Think,* Alan Jacobs (2017) described the state of thinking in America as "depressing" (p. 12). He illustrated the problem by listing the errors in fallacy used to describe poor thinking in society:

> anchoring, availability cascades, confirmation bias, the Dunning-Kruger effect, the endowment effect, framing effects, group attribution errors, halo effects, ingroup and outgroup homogeneity biases, recency illusions…that's a small selection, but even so: what a list. What a chronicle of ineptitude, arrogance, sheer dumbassery. So much gone wrong, in so many ways, with such devastating consequences for selves and societies. (Jacobs, 2017, p. 12).

Though Jacob's use of term *thinking* might be misguided, his concern is relevant to those in science – including agriculture. While *thinking* encompasses a variety of cognitive processes, literacy focuses on one's ability to critically analyze and comprehend (National Research Council, 2000). Miller (2010) stated "the health of American democracy in the twenty-first century will depend on the development of a larger number of scientifically literate citizens" (p. 241). Informed citizens in a democratic society have an increasingly important role in determining outcomes of scientific policy (Durant et al., 1989; Miller, 1983, 1998, 2004; Miller & Pardo, 2000). As the principal investigator for a series of studies sponsored by the National Science Foundation, Miller (2004) argued that a scientifically literate citizen must have, "(1) a basic vocabulary of scientific terms and constructs; and (2) a general understanding of the nature of scientific inquiry" (p. 273). Although Durant et al. (1989) claimed science to be society's greatest achievement, they reported that the general public has little understanding of the scientific system. Based on a series of studies, Miller (2004) reported that only approximately 17 percent of U.S. adults measured

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were considered scientifically literate. Further, a review of major literature focused on the study of science conducted by Osborne et al. (2003) revealed a declining interest for young people to pursue education and careers in science.

Scientific literacy is a term that has been often used in the discussion of science education reform, but has also been misunderstood (Fasce & Picó, 2019). Norris and Phillips (2003) made the distinction between primary literacy, which is the ability to read and write, and derived literacy, which is "knowledgeability, learning, and education" (p. 224). Making a distinction between *science literacy* and *scientific literacy* is important in properly discussing both (Roberts, 2007). Science literacy refers to the technical knowledge of science and is considered the short-term view (Holbrook & Rannikmae, 2009). Scientific literacy, in contrast, incudes the development of life skills, focuses on the application of science to real-world problems, and "recognizes the need for reasoning skills in a social context, and above all, this view recognizes that scientific literacy is for all, having little to do with science teaching solely focusing on a career in science" (Holbrook & Rannikmae, 2009, p. 278).

Gräber et al. (2001) placed views of scientific literacy on a continuum and proposed a Venn-diagram model visually depicting the roles of subject competence, ethical competence, and social competence. This continuum of beliefs on scientific literacy has made the identification of a single definition of scientific literacy difficult. PISA defined scientific literacy by outlining three dimensions – scientific concepts, scientific processes, and scientific situations (OECD, 2007). UNESCO defined scientific literacy as, "the capability to function with understanding and confidence, and at appropriate levels, in ways that bring about empowerment in the world of scientific and technological ideas" (p. 15). Holbrook and Rannikmae (1997) defined scientific and technological literacy as "developing the ability to creatively utilize sound science knowledge in everyday life or in a career, to solve problems, make decisions and hence improve the quality of life" (p. 15). Each definition included the need to use sound scientific knowledge to solve problems, make decisions, and advance society. This concept is extended by Godin and Gingras (2000) to include a *scientific and technological culture* (S&T) whereby a society values and builds scientific literacy to enable citizens to be critical consumers of science and technology that they regularly encounter, and to consider the impact of such on health and nutrition.

The desire for a S&T culture in agriculture has also grown (Scherer et al., 2019). Although the early principles of school-based agricultural education (SBAE) were focused on preparing youth in skills related to farming, curriculum objectives also included applying scientific knowledge to solve problems and think critically (National Research Council, 1988). McKim et al. (2017) addressed the "call for agricultural educators to illuminate the links between science and society" (p. 98) similar to the call by Godin and Gringras (2000). Their study categorized SBAE teachers into three categories: science illuminators, illumination attempters, and vocational purists. Mckim et al. (2017) stated that if all educators, regardless of category, will acknowledge "science as foundational to, and already integrated within, all aspects of SBAE, our focus switches from learning content . . . to simply developing the teaching skills to allow the scientific concepts to surface within the valuable agriculture concepts and ideas" (p. 107).

Pearson et al. (2013) developed and tested a model of science-in-career and technical education (CTE) curriculum integration using a seven-element pedagogical framework that included lessons "through which students not only learned the factual information of science, but also engaged in the more complex interactions of scientific concepts and principles and scientific inquiry" (p. 166). The study found that the science-in-CTE interventions had a significant positive effect on students' post-test science achievement for the second, third, and fourth quartiles of a semester-long study. Pearson et al. (2013) recommended further research into science and CTE integration with an emphasis on inquiry-based instruction (IBI). Wells et al. (2015) claimed that IBI "encourages the curiosity of students while developing critical thinking skills" (p. 173) and that "agriculture teachers have the unique ability to develop science and math skills through teaching agriculture in a way that goes beyond the memorization of facts" (p. 173). The National

Research Council (2012) defines critical thinking as an individual's ability "to question assumptions, analyze evidence, and come to well-reasoned conclusions about complex issues. It means being able to see the world from multiple perspectives and understand the potential biases that influence our own thinking" (p. 22). Within the context of this study, participants were tasked to think critically during the research activity as it pertains to their scientific literacy of genetically modified organisms (GMO).

The expected benefits of contextualized IBI are supported by a number of researchers in agricultural education (Blaschweid, 2002; Dale et al., 2017; Parr et al., 2006; Thoron & Myers, 2011). Balschweid (2002) found that after a yearlong biology course using the context of animal agriculture, 90% of students reported that the course helped them understand the relationship between science and agriculture. Thoron and Myers (2011) reported that IBI benefitted students' retention of agriscience course content knowledge. Students who completed agricultural education courses in high school had higher agricultural literacy scores than those who did not take agriculture courses (Dale et al., 2017). These studies highlight the idea that students can have positive learning experiences and gain content knowledge in science curriculum such as biotechnology and genomics when the appropriate structure and resources are utilized to deliver content (Mueller et al., 2015). Highlighting the core content already present in agriculture allows both the core concepts and the agricultural concepts to be enhanced (Parr et al., 2006). Key to each of these studies is purposeful, planned, and sustained instruction of both science and math in agriculture.

Contextual teaching has been shown in certain settings to lead to enhanced learning, but there is mounting evidence that the results are not always positive. Although science, technology, engineering, and math (STEM) topics have become more prominent in agricultural curriculum, Despain et al. (2016) challenged the notion that contextualized IBI led to deeper learning in concluding that students in agricultural biology score lower on an end-of-course exam than students in a general biology course. Mowen et al. (2007) identified biotechnology teachers to possibly be lacking in confidence and/or content knowledge as it relates to them being educators on the subject matter. Further, Boone et al. (2006) and Wilson et al. (2002) found that SBAE teachers accurately perceived that they lacked the knowledge to teach biotechnology.

Specifically related to GMOs, Rumble et al. (2016) found the majority of undergraduate college students surveyed to be either likely or extremely likely to consume products from a genetically modified (GM) citrus tree. However, of those surveyed, the only construct students found valuable in GM products was their relative advantage to non-GM products (Rumble et al., 2016). Powell (2013) concluded that contrary to popular beliefs, "many consumers [in Europe] do purchase, or are willing to purchase, GM foods" (p. 200). "Consumers' beliefs about risks and benefits were found to be strongly embedded in more general attitude domains such as attitude towards nature and attitude towards technology" (Brendahl, 2001, p. 53), ultimately leading to their purchasing intentions.

## Conceptual Framework

This study is framed by the comprehensive hierarchical model of scientific literacy proposed by Bybee (1997). This model focuses on the long-term view of scientific literacy and is meaningful for school purposes (Holbrook & Rannikmae, 2009). Under this model, scientific literacy is considered at four functional levels described in Table 1.

**Table 1**

*Dimensions of Scientific Literacy (Bybee, 1997)*

| Dimension | Indicators |
|---|---|
| Nominal Scientific Literacy | · Identifies terms, questions, as scientific.<br>· Demonstrates misconceptions.<br>· Has naïve explanations.<br>· Shows minimal understanding. |
| Functional Scientific Literacy | · Uses scientific vocabulary.<br>· Defines terms correctly.<br>· Memorizes special responses.<br>· Understands only a specific need or activity. |
| Conceptual and Procedural Scientific Literacy | · Understands conceptual schemes of science.<br>· Understands procedural knowledge and skills of science.<br>· Understands relationships among parts and whole of science.<br>· Understands organizing principles, disciplines, and processes of science. |
| Multidimensional Scientific Literacy | · Understands the place of science among other disciplines.<br>· Knows the history of science.<br>· Knows the nature of science.<br>· Understands the interactions between science and society. |

**Purpose of the Study**

The American Association for the Advancement of Science (AAAS, 1993), in their Project 2061 Benchmarks for Science Literacy, describe scientifically literate citizens as those that can "use the habits of mind and knowledge of science, mathematics, and technology they have acquired to think about and make sense of many of the ideas, claims, and events that they encounter in everyday life" (p. 322). Furthermore, those personal abstractions should serve as the basis for decision making and action (AAAS, 1993). In light of the call from many (National Research Council, 1988; McKim et al., 2017) to develop scientifically literate students in agriculture, it is important to explore if students enrolled in SBAE, and that have been taught GMO relevant science, are advancing in the dimensions of scientific literacy as intended. The purpose of this study is to engage students in conversations about GM foods to assess their current dimension of scientific literacy. Five research objectives guided this study:

1. Identify students' intentions to consume GMOs.
2. Determine the validity of students' theories about the process of genetic modification.
3. Determine students' science and agricultural knowledge relevant to the process of genetic modification of foods.
4. Explain students' scientific literacy dimension of GMO-related science concepts.
5. Describe where students report to have been taught about GMOs.

## Methods and Procedures

Methodology for this study was patterned after the *Private Universe Project* (Schneps & Sadler, 1989), which asked students to describe how seasonal changes occur to understand their contextualization of science principles following instruction. The study was exploratory in nature. As such, the goal was to "get an idea of or explore an area of research that is not well understood. Rarely do these questions provide definitive answers; rather, they lead to a stronger focus for subsequent research" (Privitera, 2017, p. 167). We chose GMOs as our context, not because of our interest in GMOs, but rather our interest in identifying a concept that integrated both the science and agricultural concepts taught to this population and that provided a context for students to demonstrate a progression in dimensions of scientific literacy. Figure 1 outlined the state science standard taught in the seventh grade to these students. The eighth-grade agricultural education standards also included "discuss genetically modified organisms" and referenced the Oklahoma science standard included in this study. These standards explicitly outline the intended curricular connections between science concepts and GMOs as an agricultural practice. It is important to understand that these standards are what is *purported* to be taught – we are not making any assumption as to the fidelity of that instruction. Rather, we are engaging with students at a stage in their education that should have exposed them to the concepts of genetic modification.

The population of interest in this non-experimental, descriptive study (Privitera, 2017) was all secondary agricultural education students that attended the agriculture in Oklahoma event (*N =110).* Forty-nine (44.5 % of the population) of the students provided the necessary documentation required by Oklahoma State University human subjects research (IRB) and participated in the study. A census approach was employed based on the recommendation of Krejcie and Morgan (1970) since the population size was fewer than 300. Twenty students were in eighth grade, twenty were in ninth grade, eight were in tenth grade, and one reported to be in eleventh grade. There were 28 males and 21 females. Students were attending an educational workshop that included eight different stations related to agricultural practices in Oklahoma. During the fourth rotation, students were asked to engage in one-on-one conversations about GMOs with facilitators of the workshop. In an effort to remain as unobtrusive as possible (Privitera, 2017) small cameras were staged at each station recording the interaction. A facilitation guide was created that included prompts and a discussion flow guide.

**Figure 1**

*Oklahoma 7th Grade Science Standard: MS-LS3-1 Heredity: Inheritance and Variation of Traits*

**7TH GRADE**

**MS-LS3-1 Heredity: Inheritance and Variation of Traits**

| Science & Engineering Practices | Disciplinary Core Ideas | Performance Expectations |
|---|---|---|
| ❶ Asking questions (for science) and defining problems (for engineering)<br>❷ **Developing and using models**<br>**Modeling in 6–8 builds on K–5 experiences and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems.**<br>**• Develop and use a model to describe phenomena.**<br>❸ Planning and carrying out investigations<br>❹ Analyzing and interpreting data<br>❺ Using mathematics and computational thinking<br>❻ Constructing explanations (for science) and designing solutions (for engineering)<br>❼ Engaging in argument from evidence<br>❽ Obtaining, evaluating, and communicating information | **Inheritance of Traits:**<br>• Genes are located in the chromosomes of cells, with each chromosome pair containing two variants of each of many distinct genes. Each distinct gene chiefly controls the production of specific proteins, which in turn affects the traits of the individual.<br>• Changes (mutations) to genes can result in changes to proteins, which can affect the structures and functions of the organism and thereby change traits.<br>**Variation of Traits:**<br>• In addition to variations that arise from sexual reproduction, genetic information can be altered because of mutations.<br>• Though rare, mutations may result in changes to the structure and function of proteins.<br>• Some changes are beneficial, others harmful, and some neutral to the organism. | **MS-LS3-1**<br>*Students who demonstrate understanding can:*<br>**Develop and use a model to describe why structural changes to genes (mutations) located on chromosomes may affect proteins and may result in harmful, beneficial, or neutral effects to the structure and function of the organism.**<br>**Clarification Statement:**<br>Emphasis is on conceptual understanding that changes in genetic material may result in making different proteins. Examples: Radiation treated plants, genetically modified organisms (e.g. roundup resistant crops, bioluminescence), mutations both harmful and beneficial.<br>**Assessment Boundary:**<br>Assessment does not include specific changes at the molecular level, mechanisms for protein synthesis, or specific types of mutations. |

In conjunction with a professor of plant genetics, a facilitation guide was developed that focused the discussion on three major concepts critical to describing GMOs: (a) genetic modification, (b) deoxyribonucleic acid (DNA) processes, and (c) protein synthesis. Prompts were created for each of the three concepts aligning with Bybee's (1997) dimensions of scientific literacy. Students were first asked the planned question and allowed to independently respond. Following that initial response, facilitators prompted students with information to identify the level of exposure following the developed protocol. Prior to the study, the protocol was pilot tested using 10 students not involved with the study. Those interactions were recorded and then viewed by the research team to further refine the protocol and standardize administration.

Once the video was captured, an interval, naturalistic observation method (Privitera, 2017) was used by the research team. A scoring protocol was developed that aligned with the three key GMO concepts and quantified the interaction. The protocol guided each student conversation and followed a scripted flow:

1. Determine the student's intent to consume GM foods.
2. Assess the four dimensions of scientific literacy for the three key scientific concepts: (a) genetic modification, (b) DNA, (c) protein synthesis.

3. Prompt the student in areas of weakness to further understand their understanding or lack thereof.
4. Determine if the student provided a valid theory, flawed theory, or no theory to support their intention to consume a GM product.

An example of a portion of the protocol is shown in Figure 2. Prior to scoring the videos, the research team watched 15 of the videos, to normalize scoring. An interrater reliability of .87 was established, and it was determined that the protocol and team were scoring videos with integrity. The research team watched each of the videos, scored independently, and then negotiated the final assessments if discrepancies were found. As needed, negotiation of discrepancies followed a systematic process, allowing all team members to voice their interpretations and share evidence, which allowed the research team to achieve consensus through deliberation (Lincoln & Guba, 1985). Data were entered into a SPSS Version 27 and then analyzed.

**Figure 2**

*Selected Section of Video Scoring Protocol Demonstrating Assessment of Dimensions of Scientific Literacy in the Understanding of Genetic Modification.*

| | | |
|---|---|---|
| **Concept 1A: Define a GMO**<br>Nominal Scientific Literacy | **Yes**_______ **No**_______ | **G –**<br>**M –**<br>**O –** |
| **Concept 1B: Explain GMOs**<br>Functional Scientific Literacy | **Yes**______ **w/Prompting**______ **No**_______ | **Description -** |
| **Concept 1C: Apply GMOs to Agriculture**<br>Conceptual and Procedural Scientific Literacy | **Yes**______ **w/Prompting**______ **No**_______ | **How?** |
| **Concept 1D: Apply GMOs to Agriculture**<br>Multidimensional Scientific Literacy | **Yes**______ **w/Prompting**______ **No**_______ | |

To address base level knowledge of GMOs, a researcher-created GMO criterion-referenced exam was created pulling from test banks created by the Food and Drug Administration (FDA), General Mills, Monsanto, and the United States Department of Agriculture (USDA). A panel of experts including professors, SBAE instructors, and agricultural education faculty assessed the instrument to establish both face and content validity (Creswell, 2008). The final revised exam contained 30 multiple-choice questions. Though reliability of criterion-referenced exams is difficult to measure, the eight suggestions to improve reliability, provided by Wiersma and Jurs (1990), were considered in the design. The Kuder-Richardson 20 (KR20) formula (Cronbach, 1970) was used to assess reliability. The measure produced a KR20 coefficient of .42, below the suggested .5 level (Kane, 1986). Though this should be considered, and is perhaps a limitation, Kane (1986) described the complex role of reliability of criterion-referenced exams in response to the opinion of Popham and Husek (1969) that “variability is not a necessary condition for a good criterion-referenced test” (p. 3). “If the principle use of the test scores is instructional planning, and instruction is not highly individualized, information on group performance may be adequate” (Kane, 1986, p. 224). In this study, instruction was not individualized, and students consistently responded incorrectly (consistent coding of a “0”) leading to less variability, and thus, reliability as defined by Cronbach (1970). As such, analysis proceeded and focused on group means.

## Findings

The findings related to the first and second research objectives are found in table 4 which outlines the frequency of students' intentions to consume a GMO product, their theory designation, and the average test score for the group. Thirty students reported they would eat a GMO product, but only four of those provided a valid rational. Only four reported they would not consume a GMO product, and all held either flawed theories or had no theory at all. Fifteen students were indifferent when asked about the consumption of GMO products, of which most held no theory as expected.

**Table 1**

*Students' Intention to Consume GM Foods and their Theory*

| Student Response | *f* | Theory | *f* | Test Average |
|---|---|---|---|---|
| Yes | 30 | Valid | 4 | 56% |
| | | Flawed | 20 | 44% |
| | | None | 6 | 39% |
| No | 4 | Valid | 0 | n/a |
| | | Flawed | 1 | 40% |
| | | None | 3 | 39% |
| Indifferent | 15 | Valid | 1 | 48% |
| | | Flawed | 2 | 26% |
| | | None | 12 | 41% |

*Note.* Student response in column one is related to the question, would you eat a GMO product?

In response to the third and fourth research objectives (see Table 2), it was found that 28 students were at the nominal dimension of genetic modification, but they were not able to extend into more advanced dimensions. Only 14 of the 49 students knew the basic terminology of DNA and only 2 could extend their discussion of DNA beyond basic concepts. Students did not understand the concept of protein synthesis as all 49 had no conceptualization of the concept. Students that had a valid theory ($n$ =4) had the highest test scores (56%), while the lowest test score came from students that were indifferent and provided flawed theories.

**Table 2**

*Student Conceptualization of Genetic Modification*

| Concept | Level of taxonomy | Yes | Yes w/Prompting | No |
|---|---|---|---|---|
| GMO | Nominal | 28 | 0 | 21 |
| | Functional | 4 | 9 | 36 |
| | Conceptual & Procedural | 2 | 3 | 44 |
| | Multidimensional | 0 | 0 | 49 |
| DNA | Nominal | 14 | 8 | 27 |
| | Functional | 2 | 3 | 44 |
| | Conceptual & Procedural | 1 | 0 | 48 |
| | Multidimensional | 0 | 0 | 49 |

| | | | | |
|---|---|---|---|---|
| Protein Synthesis | Nominal | 0 | 0 | 49 |
| | Functional | 0 | 0 | 49 |
| | Conceptual & Procedural | 0 | 0 | 49 |
| | Multidimensional | 0 | 0 | 49 |

Research objective five was related to course exposure to genetic modification. Students reported the most exposure to GMOs in their foundational agriscience course. In contrast, DNA was reported to be taught most often in science courses. Twelve of the students reported they had received no exposure to GMOs, and six students reported they had never been taught about DNA. Only 14 of the 49 students reported learning about DNA in the agricultural curriculum (see Table 3).

**Table 3**

*Students Course Experiences Related to Genetic Modification*

| Concept | Ag 1 | Horticulture | Science | No Exposure |
|---|---|---|---|---|
| GMOs | 24 | 7 | 19 | 12 |
| Plant Science | 21 | 9 | 20 | 6 |
| DNA | 14 | 1 | 33 | 6 |

*Note.* Frequencies are presented based on the class reported to provide exposure to genetic modification.

## Conclusions

**Conclusion 1: The majority of students expressed they would consume GMO products, but had an invalid, or no theory to support that decision.**

The researchers found that although the majority of students reported that they would consume GMO products, only 10% of participants had a valid theory backing their intention to consume GMOs, which demonstrated similar findings to Miller (2004) who found only 17% of adults to be scientifically literate. Even the participants who were considered indifferent in their intention still indicated that either they already have eaten or were willing to eat GM foods. The results support Rumble et al. (2016), and Powell's (2013) finding that people are likely to purchase GM food products. Although these findings align with previous studies on the intentions of consumers, the researchers also found the theories of the majority of participants to be either flawed or absent of a theory entirely. Students sought to create scientifically based theories to explain their intentions, but those theories were based on inadequate science concepts, and were thus flawed.

**Conclusion 2: Students were unable to extend beyond the nominal dimension of scientific literacy.**

Fifty-seven percent of students demonstrated a basic knowledge of GMOs by defining the letters in the acronym. Very few students could demonstrate understanding of GMOs, and only 4% could apply the GMO principles to agriculture without prompting. Less than 29% of participants demonstrated a basic knowledge of DNA without prompting, and the majority of students demonstrated no knowledge of DNA. Only two students demonstrated an understanding of DNA, and only one participant could apply DNA to genetic modification. In regard to protein synthesis, none of the students demonstrated knowledge, understanding, or application of the process, indicating that no students fully understood the process of genetic modification. This conclusion comes contrary to multiple studies (Pearson et al., 2013; Thoron &

Myers, 2011; Wells et al., 2013) as agriculture students struggled to make both science and agriculture connections in this study.

**Conclusion 3: Students have limited experiences in their coursework related to genetic modification.**

Almost one in four students reported that they had been provided no experiences in their coursework related to GMOs. Students could not demonstrate a contextual understanding of science principles or agriculture principles as they related to GMOs, in spite of the claims set forth by Wells et al. (2013) and the purported Oklahoma standards for seventh grade science and eighth grade agricultural, in which all of the students had completed or were enrolled in.

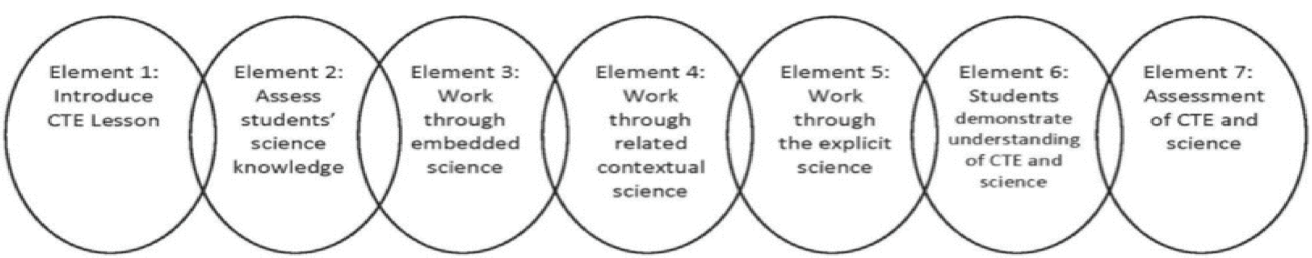
## Implications and Discussion

The reported levels of students' knowledge, understanding, and application of genetic modification, DNA, and protein synthesis is low. The state standards provided in Figure 1 not only clearly outline all of the content of interest in this study, it also directly names genetic modification and science process standards that include critical thinking and analysis. Compounding the problem, standards in agricultural education also explicitly note "discussion of genetically modified organisms" as a goal of courses these students completed. What happened? Perhaps McKim et al. (2017) described this vocationally minded agricultural educator that does not view their role as a teacher of science content. The issue with McKim et al.'s (2017) assertion is that they shared that the science is naturally existing within the agriculture and that pulls all types of educators together. The naturally existing science was not found in this study. Students were quite apathetic to the science of GMO's, were confident in their decision to consume them, and seem to confirm some of Jacobs (2017) concerns. Perhaps this was a classic example of confirmation bias whereby the agricultural tribe is accepting of GMO products, and as such, so was this population. This possibility would fall under confirmation bias (Jacobs, 2017) and poses challenges. The issue is really not whether they accept GMO or not, the issue is do they have a valid theory as to why? Unfortunately, in the reported population, valid theories were lacking.

The model put forth by Pearson et al. (2013) depicted the ideal delivery of science in the context of agriculture (see Figure 3). Element two, at least in this population, is incredibly important. Though many in agricultural education have shared that you simply introduce the agricultural content – for us that was GMOs – and then "work through" the embedded science, it appeared in this study that "work" means teach it beginning at the lowest knowledge level. Our findings indicate that to move students to higher dimensions of scientific literacy, element two, followed by science concept remediation, might be critical in our instructional methods.

**Figure 3**

*The Science-in-CTE Pedagogic Framework*



How does this model proceed if science educators are not ensuring students understand the basic science principles? Is it then the job of agricultural educators to not only support science educators by contextualizing the content, but also teaching it at a fundamental level? Gärber's (2001) model of scientific literacy highlights the importance of subject competence, values, and the ability to apply science to matters of societal interest. Subject competence seems to be a limiting factor for students in this sample. That higher order perspective is the discussion of scientific literacy and requires all individuals to be engaged and aware of the challenge. Students in this study started with mostly inaccurate or absent theories forcing them to rely on their own reason to formulate a rationale or process – which was flawed the majority of the time. What are the implications for agriculture if agricultural education students continue to struggle to complete tasks like the one presented in this exercise? This sample seemed to indicate that SBAE students were not scientifically literate when discussing GM foods.

The findings of Thoron and Myers (2011) and Wells et al. (2015), who found IBI used in SBAE classrooms to drive student interest and increase retention of agronomic topics, does not align with the findings of this study. Though it is recognized the two studies focused on different populations, students in this study had little knowledge and struggled to understand and apply the topics related to the GM process in agriculture. This begs the questions, are SBAE students learning what we think they are, and do they have the science knowledge we assume they have? Critical thinking and problem solving are key skills that students need to be able to apply in life (National Research Council, 2000). SBAE students have an advantage according to the National Research Council (1988) as they are being taught to apply scientific knowledge, allowing them to solve problems and think critically. This study found students struggling to explain and make connections on content that has been covered multiple times according to state standards, asking the question, are these skills being taught in today's classroom?

**Recommendations for Practice**

Teachers in SBAE should be aware of the grade-level academic standards for secondary students in their respective states in order to appropriately provide meaningful context to the principles that students are learning in other courses. Along with reviewing academic standards, inquiring with grade-level science teachers would provide an opportunity to improve the disconnect between core-academic teachers and SBAE teachers. Agricultural educators must address and interact with students' existing beliefs in order to lead them towards grounded conclusions in regard to science concepts in agriculture. Further, teachers should facilitate experiences in their lessons that require students to think critically about a subject. Bybee's (1997) dimensions of scientific literacy should be more fully discussed and integrated into curriculum to provide relevance to the need to secure knowledge of science concepts and then apply those to agricultural problems and practices. SBAE teacher educators should introduce preservice and in-service teachers to Pearson et al.'s (2013) pedagogical model as well as the dimensions of scientific literacy (Bybee, 1997). SBAE teachers should apply all seven elements of the model to their instruction to provide students with the opportunities to learn science contextually in agriculture. This includes teachers assessing students' science knowledge and working through explicit science in their lessons. SBAE teachers should seek professional development opportunities to address any limited areas of content knowledge related to science, particularly biotechnology and genetics.

**Recommendations for Research**

Although this study offered conclusions based on the stated research objectives, numerous additional questions arose during this exploratory study. These research questions include: (a) How do secondary agricultural education student's beliefs compare to those of non-ag students? (b) What are outside influences effecting a person's intentions? (c) Are SBAE teachers actually prepared to educate students on science-based curriculum? (d) Why are students struggling to be critical thinkers, and apply standards-based knowledge? (e) Is SBAE preparing students to be advocates for the agricultural industry, with a deep understanding to handle problems and questions that will arise? Replication of this study would provide valuable insight. First, this study yielded a number of methodological suggestions when using this approach. If replicated, our team would provide manipulatable materials to demonstrate genetic modification rather than the paper and pencil format used in this study. Genetic modification did not lend itself well to simple drawings. Second, replication in other states where the curriculum is more science focused would provide interesting insight into the impact of more scientifically focused curriculum on one's ability to think well about practices in agriculture.

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