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The Effectiveness of a Metacognitive Strategy during the Reading Process on Cognitive Allocation and Subject Matter Retention

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Abstract

Metacognition is an important skill required for improving students' reading comprehension ability. Studies have reported effectiveness of metacognitive reading strategies to increase reading comprehension and information retention. However, there is limited research utilizing eye-tracking technology to explore the effectiveness of metacognitive reading strategies. This experimental study utilized eye-tracking technology on 40 undergraduate students to investigate the effectiveness of a metacognitive strategy on reading comprehension outcomes. The Survey, Question, Read, Respond, Recite, Record, and Review (SQ5R) strategy was used as the metacognitive reading strategy intervention. Participants' eye movements were recorded during the reading process. Reading comprehension was assessed before and after watching the SQ5R intervention. This study revealed that participants adopted the SQ5R when reading scientific text, which enabled the students to better comprehend and retain more information. Results suggest that agricultural educators should incorporate the SQ5R metacognitive reading strategy into the design of agriscience reading materials to improve students' reading skills and their ability to comprehensively understand complex and controversial issues in agriculture.

***Keywords*:** metacognition; agricultural education; SQ5R reading strategy; reading comprehension; eye-tracking

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Introduction

Reading and understanding scientific text proficiently is one of the most important foundational abilities necessary for students to expand their knowledge (Cromley et al., 2010; Glynn et al., 1994). However, students often perceive reading scientific text as difficult because of the use of many abstract terms (Gear, 2008). Many students lack the knowledge of how to understand essential information in scientific text (Baier, 2011). According to the 2015 National Assessment of Educational Progress reading report (the latest report available), the majority, 63%, of 12^{th} grade students were not proficient readers. Non-proficient readers may encounter difficulties in academic performance when they attend college (Savolainen et al., 2008). Given the difficulties of understanding scientific text, students should learn and practice reading strategy so they can develop their reading skills (Griffin et al., 2019).

Scholars and educators have been striving to provide effective reading strategies to improve students' reading comprehension skills (Asiri & Momani, 2017; Artis, 2008; Caverly et al., 2000). Reading comprehension, a complex cognitive process, has been defined as "a process of making meaning from text" (Woolley, 2011, p. 15). Previous studies have discussed various reading strategies for improving students' reading comprehension skills (Larasati et al., 2018; Leopold & Leutner, 2015; Tok, 2013). According to researchers, metacognition (thinking about how you are thinking) reading skill has been used widely by many proficient readers (Leopold, & Leutner, 2015; Otero, 2002). Previous studies have demonstrated the importance of adopting metacognitive reading strategy for science learning (Otero, 2002; Pressley & Gaskins, 2006). For example, Pressley and Gaskins (2006) stated that proficient readers engage in the metacognitive process to foster their reading process. Additionally, Otero (2002) emphasized the importance of utilizing a self-regulating reading strategy for readers who have encountered challenges in understanding scientific information in order to avoid comprehension failure.

The agriculture industry faces many complex and controversial issues, such as food security, climate change, and water conservation (Lamm et al., 2018). Many of these topics have permeated into agriscience classrooms (Owens et al., 2017). Because agricultural students are expected to develop strong reading skills to understand and evaluate these critical issues (Park & Osborne, 2005; 2007), there is a need to identify and incorporate more efficient instructional reading strategies into agricultural education to facilitate students' reading process (Gordon & Ball, 2017; Hasselquist et al., 2019; McKim et al., 2016; Park & Osborne, 2005; 2007). For example, Gordon and Ball (2017) emphasized the importance of integrating metacognitive processes into agricultural education as a necessary component to enhance students' understanding of complex agricultural issues. However, previous studies have found that agricultural educators have struggled to incorporate effective instructional reading strategies into their programs (Park & Osborne, 2006a; 2006b). In addition, agriscience teachers have been regarded as the group most opposed to applying content reading in their classrooms (O' Brien & Stewart, 1990). Many pre-service agricultural educators reject content area readings (Warner & Myers, 2013). Thus, it is imperative to identify effective instructional reading strategies that agricultural educators would be willing to incorporate into their classrooms to improve students' reading skills.

Metacognition

Metacognition was first proposed by Flavell (1976). He defined metacognition as using one's own cognition to understand information and regulate cognitive processes to achieve active learning. In 2002, Flavell and other researchers described metacognition as an information process of "cognition about cognition' or 'thinking about thinking" (Flavell et al., 2002, p. 175). These researchers also emphasized the essential role played by metacognition in reading comprehension and memorization (Flavell et al., 2002). By utilizing metacognitive strategies, such as planning, monitoring, and evaluating, students could be aware of their own cognitive process and adopt appropriate strategies to comprehend reading materials (Flavell, 1992). Also, practicing metacognitive strategies can mitigate students' negative thoughts regarding reading scientific texts and positively improve their learning performances (Veenman et al, 2006; Zhang, 2018). Teaching metacognitive strategies should be a primary goal for educators to help students learn how to read and expand their knowledge (Baker, 2002; 2008).

Metacognitive Strategies

A wide range of effective metacognitive strategies have been developed by scholars for scientific reading (Leopold & Leutner, 2015), language learning (O' Malley & Chamot, 1990), and mathematics learning (Tok, 2013; Yang, 2012). In 1941, Francis P. Robinson introduced a metacognitive strategy, which represents a step-by-step process leading students to complete reading tasks by surveying, questioning, reading, reciting, reviewing (SQ3R) messages (Robinson, 1946). Robinson (1961) stated SQ3R strategy was an effective reading technique to identify important information and transfer it into long-term memory. Later, other reading strategies have been proposed based on modifications of the basic original SQ3R. For instance, Thomas and Robinson (1972) developed SQ4R by adding an additional 'Record' step. Further, SQ3R has also been developed into SQP4R, an acronym of Survey, Question, Predicting, Reading, Reflect, Recite and Review (Slavin, 2006).

Pauk (1984) developed SQ5R by adding an additional step of 'Respond' to SQ4R, which stands for Survey, Question, Read, Respond, Record, Recite, Review. Previous studies have indicated that SQ5R could help readers to manage their cognitive process and engage purposeful and active learning (Sangcharoon, 2010; Santrock, 2004). The SQ5R seven-step model begins by surveying (S) the main ideas and browsing through the title and section headings to general background information they need to understand or retain from the reading text. At this time, readers should consider how much time and effort they need to understand the text. Question (Q) is the SQ5R step of anticipating or predicting specific questions that they should answer later to guide their comprehension. The third step of SQ5R requires students to actively read (R) through the entire text to effectively engage with the content and understand the authors' objectives. Actively reading allows students to be aware of their cognitive process and monitor their comprehension as well as self-regulate their reading strategies to improve their understanding.

Following the completion of reading, students need to respond (R) to the questions generated in step 2. Record (R) then allows readers to move back through the text to take mental notes of its main concepts. The goal of the recite (R) step is to reflect on what readers have read by recalling the answers generated from Question. The recite step can help students reconstruct the content of the reading materials to improve comprehension and transfer information from short-term memory to long-term memory. The final step of SQ5R is review (R), which helps readers capture the important concepts and main points for long-term memory. Review can help readers purposefully embed the main points of the message from the reading within their memory for easier retrieval later. The SQ5R is a self-directed and self-regulated process; however, it is only effective if readers utilize it consciously and purposefully (Sangcharoon, 2010). Once the strategy is learned and regularly practiced, readers will be able to read at a faster pace, identify main ideas, and retain information for long-term memory (Sangcharoon, 2010).

Metacognition Measurement

The metacognitive process is a multifaceted complex process including individuals' motivational responses and self-regulated process (Lai, 2011; Schraw & Moshman, 1995). It is not easy to observe or to explain the metacognitive process as individuals may not even be aware of their cognitive process. Thus, it is important to apply a measurement precisely during actual reading activities when the cognitive process is being engaged (Veenman et al., 2003). The self-report, interview, and thinking aloud off-line approaches have been used to evaluate metacognitive activities. However, these off-line assessments may not accurately reflect what participants have done during the cognitive process (Veenman, 2005). Compared to these off-line methods, online-methods, which can be utilized during the cognitive processing, are more accurate for evaluating participants' cognitive process (Veenman, 2005). Researchers have indicated that eye-tracking assessment, an online technology, can provide valid and reliable real time information compared with off-line assessments (Roderer & Roebers, 2010; Scheiter & Eitel, 2016; Scheiter & Van Gog, 2009). For example, Rayner and Raney (1996) indicated that eye-movement measurement, a behavior indicator, is one of the most precise methods to evaluate cognitive process. A study which assessed participants' metacognitive activities found that eye-movement data was more objective and reliable to reveal complex metacognitive process compared with a self-report questionnaire (Susac et al., 2014).

Previous researchers have identified eye-movement data as a reliable indicator to understand the cognitive process which occurs during reading. Eye-movement data can allow researchers to understand what individuals look at, in what order, and how long they engage with the information (Antonietti et al., 2015; Kinnunen & Vauras, 1995; Kinnunen et al., 1998; Rayner & Well, 1996; Roderer & Roebers, 2010). Eye fixation is "the period of time when the eyes remain fairly still and new information is acquired from the visual array" (Rayner, 2009, p.1458). Eye-fixation duration and frequency not only reflect the attentional process but also the metacognitive process which occurs during reading (Brunyé et al., 2019; Duchowski, 2007; Mason et al., 2015). Previous studies found a strong relationship between eye-fixation and the cognitive process (Hayhoe et al., 1998; Just & Carpenter, 1980; Roderer,1998). According to *A Theory of Reading: From Eye Fixations to Comprehension* proposed by Just and Carpenter (1980), eye fixation duration on each word of reading text was recognized as a function of involvement of the cognitive process (Just & Carpenter, 1980). Just and Carpenter (1987) also argued, "the time that a reader spends on various parts of a text and the places where he fixates or rereads the text are excellent indices of the ongoing psychological process" (p. 5).

A number of researchers have utilized eye-movement fixation behavior to explore the cognitive process which occurred during the reading process (Hayhoe et al., 1998; Karatekin, 2007; Legge et al., 1997; Reichle et al., 1998; Reilly, 1993; Reilly & O'Regan, 1998). These studies revealed that utilizing metacognitive skills could facilitate reading comprehension. For example, a study which investigated online reading patterns and comprehension by utilizing eye-fixation concluded that metacognitive skills played an important role in fluent reading process (Kang, 2014). Similar, another study which explored readers' eye fixations while taking an English test found that using metacognitive strategies could lead readers to read more efficaciously (Bax, 2013). Rayner et al. (2006) also assessed the reading comprehension process by using eye-movement fixations (average fixation duration, number of fixations, and total fixation time). They found "it is only during the fixations that new information is encoded, because vision is suppressed during saccades (*rapid eye-movements from one place to another*) (Rayner et al., 2006, p. 242).

Previous studies have established the effectiveness of metacognitive strategies (e.g., SQ3R, SQ4R, and SQP4R) in enhancing reading comprehension. For instance, Artis (2008) demonstrated the importance of adopting SQ3R in improving students' reading comprehension ability in marketing curriculum. Also, Darnawati et al. (2018) revealed that students' learning outcomes increased significantly through the implementation of SQ3R strategy in history class. Yakupoglu (2012) found SQ4R was a very helpful instructional technique for enhancing reading achievement in students for whom English is a foreign language. A study focusing on the effectiveness of utilizing SQP4R found that it could help students gain a deeper understanding of the reading materials (Zolfaghari & Ershadimanesh, 2017). Several studies have demonstrated SQ5R metacognitive strategy's effectiveness of improving reading comprehension. For example, Sangcharoon (2010) stated the implementation of SQ5R metacognitive strategy increased ninth grade students' English reading ability. However, none of these studies utilize eye-tracking technology to explore the effects of SQ5R in the context of agricultural education.

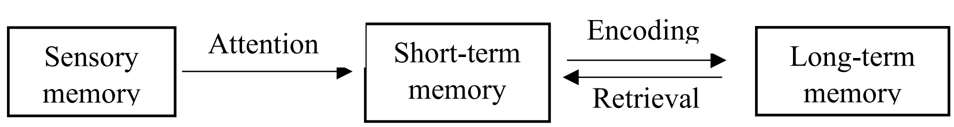
Theoretical Framework

Metacognitive reading strategy awareness theory (Flavell, 1976) was used to guide this study. Metacognitive reading strategy awareness is described as intending to regulate one's own learning by means of planning, monitoring, and evaluating the reading comprehension process (O' Malley & Chamot, 1990). Metacognitive reading strategy awareness focuses on self-regulation of the reading process to improve reading proficiency (Flavell, 1976). Readers should be aware of applying strategies to solve situational constraints and difficulties encountered in their reading process (Baker & Brown, 1984; Gourgey, 2001; Hamdan et al., 2010). Researchers indicated that metacognitively active readers are willing to utilize different metacognitive strategies to improve their reading comprehension (Devine, 1993; Singhal, 2001). Metacognitive strategy awareness not only increases readers' awareness of monitoring their reading comprehension but also yields stable and long-term improvements in reading comprehension performance (Ahmadi et al., 2013; Koda, 2005; Tang & Moore, 1992).

The second theoretical framework supporting this study was information processing theory (Figure 1). Information process theory illustrates how people engage mental activities to receive information within the learning process (Simon, 1979). According to Newell and Simon (1972), the cognitive information process includes attention, encoding, storage, and retrieval (Figure1). Each component of metacognitive strategy is designed to facilitate the information process to aid readers to recall the information effectively (Tadlock, 1978). Miller (1956) used short term memory and long-term memory to describe the information process. Each component of SQ5R metacognitive strategy aligns with information processing theory was described in Table 1. The SQ5R metacognitive strategy help students know the objectives of reading materials, extract and construct important information during the attention and encoding processes, and retain and retrieve knowledge from long-term memory.

Figure 1

Information Processing Model



Note. Information Processing Model (Miller,1956; Newell & Simon,1972)

Table 1

Theoretical Framework of SQ5R Metacognitive Strategy Aligned with the Information Process Model

Information Processing Model		SQ5R (Pauk,1984))
Attention	Surveying and questioning information prepares the cognitive process for inputting information.	Survey & Question
Encoding	Reading actively guides readers in evaluating and selecting important information.	Read

Storage (short-term & long-term memory)	Pausing for thinking gives the cognitive processing system time to extract and construct thoughts.	Respond, Record & Recite,
Retrieval	Reviewing the content helps transfer information from short-term to long-term memory.	Review

Purpose and Objective

This study aligns with the American Association for Agricultural Education's National Research Agenda's Research Priority Five: *Efficient and Effective Agricultural Education Programs* (Roberts et al., 2016). Priority five highlights the need for school-based agricultural education to "incorporate numerous factors that require a unique set of skills aside from the typical educational factors that are associated with student academic success" (p. 43). Because this study investigated the effect of a metacognitive reading strategy on students' reading comprehension using innovative eye-tracking technology, it contributes to priority five by identifying factors that can improve students' academic achievement.

This study aims to evaluate the effectiveness of SQ5R metacognitive strategy on reading comprehension performance. Specifically, eye-tracking technology was employed to compare the differences of eye-movement behaviors before and after the intervention of metacognitive strategy SQ5R. Information retention was compared through reading comprehension tests taken by students before and after watching an SQ5R intervention video. By discovering how SQ5R metacognitive strategy improve students' reading ability, agricultural educators may be able to design efficient and effective agricultural educational programs to assist students in better comprehension of agricultural issues.

Methods

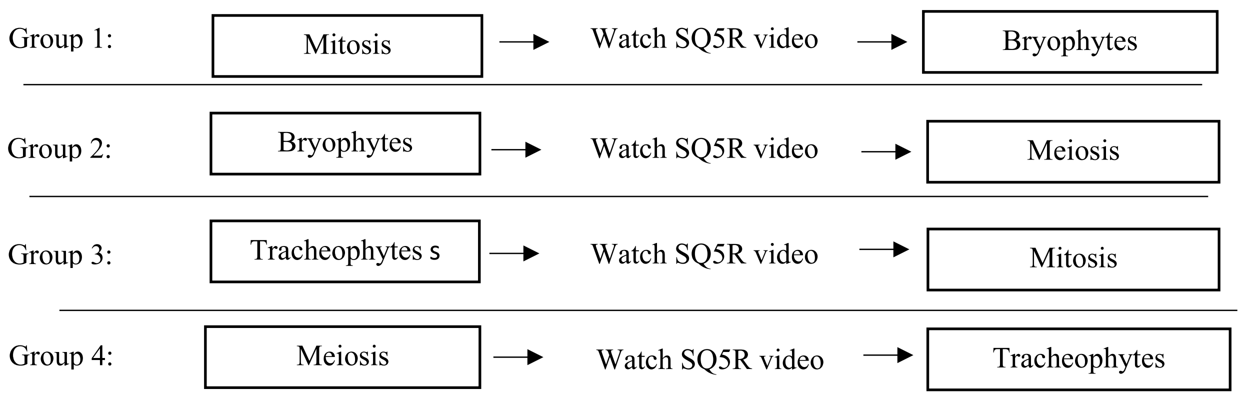
Participants and Procedure

The participants were recruited through Texas Tech University Announce, Facebook, and classroom recruitment. A total of 44 undergraduate students participated in the study. Four participants were omitted from the study due to data collection or technique errors. As a result, the convenience sample included 40 students (72% female) between 18 and 20 years of age (M_{age} = 19.82, *SD* = 1.62), majoring in Agriculture (*n* = 19), Business (*n* = 3), Kinesiology (*n* = 3), Engineering (*n* = 3), Biochemistry (*n* = 2), Computer Science (*n* = 2), Pre-nursing (*n* = 2), English (*n* = 1), Human Development and Family Sciences (*n* = 1), Advertising (*n* = 1), Art (*n* = 1), and Psychology (*n* = 1). All students have normal or corrected-to-normal vision without learning or reading disabilities.

Four short scientific narrative passages were used as stimuli in this study. These reading passages, taken from SparkNotes.com, included the topics of mitosis, meiosis, tracheophytes, and bryophytes. These four reading selections were chosen because the content was similar to science textbooks, and the difficulty level was appropriate for college students. The Flesch-Kincaid Grade Level for the mitosis passage was 12.8, for meiosis was 11.3, for bryophytes was 12.1, and for tracheophytes was 13.4. Each participant was randomly assigned to read two of the four passages. The four topical passages resulted in four combinations (Figure 2).

Figure 2

The Combination of Four Scientific Topics in Each Group



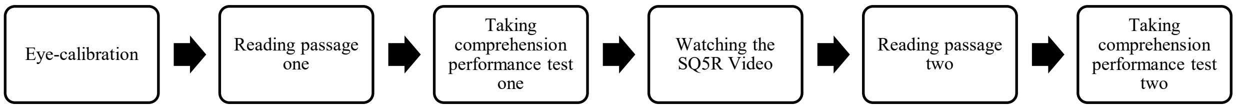
A comprehension performance test for each passage consist of three open-ended questions created by the researchers to assess the participants' reading comprehension and information retention. According to Koad (2005), reading comprehension includes three major activities: lexical information decoding, text-information extraction, and text meaning integration or construction. Lexical information decoding and text-information extraction refer to low-level reading comprehension skills, while text meaning integration or construction is a high-level reading comprehension skill (Cohen, 1994). The three open-ended questions were used to evaluate participants' recall of details from the reading materials all assessed low-level reading comprehension skill. The questionnaire was reviewed by an expert panel for content accuracy and face validity. The score was determined by making the correct responses from concept. Students' comprehension performances were assessed using a paper and pencil format.

Tobii Pro Eye-tracking technology was used to record eye-movement. A pilot study (n = 15) was conducted to examine eye-tracking technology feasibility and data usability. One of the authors scored the reading comprehension tests. A consent form describing was given to each participant. Once the participant completed the consent form, they were seated in front of a desk-top computer with Tobii Pro eye-tracking software installed. Each participant was verbally instructed on how to watch the video and how to move through each section of reading materials and questions. The eye-tracking experimental procedures are presented in Figure 3. Before the experiment started, an appropriate 30-second eye calibration was applied for each participant. Each participant read passage 1, then took comprehension performance test one. Next, each participant watched the SQ5R metacognitive strategy video. Then, each participant read passage 2 and took comprehension performance test two (Figure 3). The SQ5R metacognitive strategy video which taught each participant how to use SQ5R metacognitive strategy was a 4:02 minute video made by the researcher using PowerPoint and recorded audio. The participants were instructed to use SQ5R strategy to read the second passage and take the comprehension test two. They were asked to read silently and carefully. Participants could not return to a previous passage while taking the comprehension performance tests.

After taking comprehension test two, the participants were asked to complete a questionnaire on Qualtrics on the computer. To reduce the influence of participants' previous knowledge of the comprehension performance tests, participants were asked to rate their prior knowledge on the assigned reading material. The previous knowledge test question was "*on a scale of 1 to 5, how much did you already know about the topics presented in the reading passages? 1: None at all, 2: A small Amount, 3: A Moderate Amount, 4: A Fairly Large Amount, 5: A Huge Amount*". In addition, participants were also asked to rate how much they used SQ5R after they watched the SQ5R video. The question was *"on a scale of 1 to 5, to what extent did you* *try to use the SQ5R method? 1: None at all, 2: A small Amount, 3: A Moderate Amount, 4: A Fairly Large Amount, 5: A Huge Amount".* Upon completion of the Qualtrics instrument, $20 cash was given to the participant as compensation.

Figure 3

Eye-tracking Experiment Procedures



Data Analysis

Participants' eye movements were analyzed by creating areas of interest (AOIs). The target areas identified for AOIs were highlighted in the eye-tracking software. The AOIs were selected in the passage by choosing the relevant information in each passage, which was used to answer the open-ended questions in the comprehension performance tests. For example, the AOI in tracheophytes passage is "*this vascularization adaptation,"* which was used to answer the question " __allows tracheophytes to become more fully terrestrial." This question required participants to retrieve the relevant information: "*this vascularization adaptation allows tracheophytes to become more fully terrestrial.*" Each passage had three AOIs aligned with the three open-ended questions. The operational measures were the average of eye-movement fixation durations and the average of eye-movement fixation frequencies on the AOIs. Fixations were operationalized as "eye movements that stabilize the retina over a stationary object of interest" (Duchowski, 2007, p. 46). Fixation duration was the time that participants spent fixated on AOIs. Fixation frequency was the number of fixations on AOIs. Fixation duration percentage was the time spent on AOIs relative to time spent on the entire passage.

To examine the effectiveness of the SQ5R strategy, four mixed-design ANOVAs were conducted with each group (group 1 vs. group 2 vs. group 3 vs. group 4) as a between-subjects variable. Comprehension performance test scores (test one vs. test two), fixation duration (before watching the SQ5R video vs. after watching the SQ5R video), fixation frequency (before watching the SQ5R video vs. after watching the SQ5R video), and fixation percentage (before watching the SQ5R video vs. after watching the SQ5R video) were within-subjects variables. The two comprehension performance tests were used to compare whether students mastered the SQ5R strategy to understand the scientific passages. The mixed-design ANOVA was used to assess the equivalence of the four groups in order to examine the scientific passages' content interferences or subjects' sensitivity to the two comprehension performance tests (Ary, et al., 2018). To examine the assumption of sphericity, Mauchly's test was conducted. In this study, each variable has only two levels (before and after SQ5R intervention). According to Field (2018), "if the repeated-measures variable has only two levels then sphericity is met" (p. 492). To indicated effect size, r was calculated for mixed-design ANOVA (Field, 2018).

Results

The previous knowledge assessment indicated that the average previous knowledge of participants was a small amount (M = 2.11, SD = .86). The small amount of previous knowledge eliminated the influence of participants' previous knowledge on their reading comprehension performance tests. The average level of using SQ5R was *a moderate amount* to *a fairly large Amount* (M = 3.66, SD = .81), which indicated the majority of participants used the SQ5R metacognitive strategy. Participants' descriptive analysis of fixation duration, fixation frequencies, fixation duration percentage, and comprehension performance test scores before and after SQ5R intervention was presented in Table 2.

Table 2

Means and Standard Deviations of Average Fixation Duration, Fixation Frequencies, Fixation Duration Percentage, And Comprehension Performance Test Scores Before and After SQ5R Intervention (n = 40)

	Before Intervention		After Intervention	
	Mean	*SD*	*Mean*	*SD*
Fixation duration (seconds)	6.46	3.29	10.79	6.65
Fixation frequencies (counts)	28.03	11.38	52.03	39.36
Fixation duration percentage (%)	11.35%	.46	19.86%	.68
Comprehension performance test (points)	22.79	26.94	54.35	32.34

For the four groups' equivalences, there were non-significant main effects among the four groups in each mixed-design ANOVA (See Table 3). The non-significant main effects indicated that regardless of which passage a participant was assigned, the four groups were equivalent. In other words, there was no scientific passage content interference, or subjects' sensitivity for the two comprehension performance tests.

Table 3

Between-Subjects Main Effects of Comprehension Performance Test, Fixation Duration, Fixation Frequency, and Fixation Duration Percentage (n = 40)

Variables	*df*	*SS*	*MS*	*F*	*p*
Comprehension performance test	3	4583.25	1527.75	1.80	.17
Error	34	28850.69	848.55		
Fixation duration	3	164.30	54.98	1.93	.14
Error	36	1023.31	28.43		
Fixation frequency	3	1621.30	540.44	1.06	.38
Error	36	18392.90	510.91		
Fixation duration percentage	3	.01	.01	.73	.54
Error	36	.11			

Table 4 presents the within-subjects main effects of comprehension performance test, fixation duration, fixation frequency, and fixation duration percentage. For the comprehension performance test scores, there was a significant main effect (F (1, 34) = 20.92; p <0.001), which indicated students retained more information after they had been taught the SQ5R metacognitive strategy. The average of comprehension performance test one scores was 22.79 out of 100 points (SD = 26.94). The average of comprehension performance test two scores was 54.35 out of 100 points (SD = 32.34). There was no interaction between the comprehension performance test scores and the four groups (F (3, 34) = 1.33; p = 0.28). For the fixation duration (seconds), there was a significant main effect (F (1, 36) = 16.09, p < 0.001). Students allocated more fixation time (in seconds) on the second passage after watching the SQ5R video (M =141.92, SD = 63.69) compared to the time allocated on the first passage (M = 71.95, SD = 22.30). There was no interaction between the fixation duration and different groups (F (3, 36) = 2.29; p = 0.09).

For the fixation frequency, the main effect was significant (F (3, 36) = 25.98, p<0.001). The average fixation frequency before the intervention was 28.03 (SD = 11.38). After watching the intervention, the average of fixation frequency was 52.03 (SD = 39.36). There was no interaction between the fixation frequency and different conditions (F (3, 36) = 2.31; p = 0.09). For the fixation duration percentage, there was a significant main effect (F (1, 36) = 47.23, p < 0.001). The fixation duration percentage on AOIs before the intervention was 11.35%, which increased to 19.86% after watching the SQ5R metacognitive strategy video. Students allocated more time on the second passage both to the AOIs and to the entire passage. A significant interaction was detected between fixation duration percentage and the four groups (F (3,36) = 3.73; p = 0.02)

Table 4

Within-Subjects Main Effects of Comprehension Performance Test, Fixation Duration, Fixation Frequency, and Fixation Duration Percentage (n = 40)

Variables	*df*	*SS*	*MS*	*F*	*p*	*r**
Comprehension performance test	1	17687.10	17687.10	20.90	< .001	.62
Interaction	3	3367.46	1122.49	1.33	0.28	
Error	34	28769.88	846.17			
Fixation duration	1	358.98	358.98	16.09	< .001	.56
Interaction	3	153.61	51.20	2.29	.09	
Error	36	803.39	22.32			
Fixation frequency	1	11155.70	11155.70	25.98	< .001	.65
Interaction	3	2974.81	991.60	2.31	.09	
Error	36	15459.55	429.43			
Fixation duration percentage	1	.15	.15	47.23	< .001	.75
Interaction	3	.04	.01	3.73	.020	
Error	36	.12	.01			

*Note: *r: 0.10 = small, 0.30 = medium, 0.50 = large*

Conclusions and Discussion

Given the importance of using metacognitive strategy to improve agricultural students' reading ability, it is necessary to investigate the efficacy of specific metacognitive strategy. The present study employed eye-tracking technology to examine the effectiveness of the specific metacognitive strategy SQ5R in the context of a scientific reading task. According to the real-time eye movement behaviors observed during this experiment, participants' reading patterns changed after they watched the SQ5R video. They allocated more time to the relevant information of the passage (AOIs) and reread the relevant information significantly more frequently. Specifically, participants were able to successfully target and focus on the relevant information in the reading passage instead of skimming through the passage.

In addition, according to the theoretical framework, each component of metacognitive strategy is designed to facilitate the information process to help readers memory information effectively (Newell & Simon,1972). This study argues that participants' reading pattern changes could be due to the implementation of SQ5R leading students to extract the important information and input it into their memory system. Also, the significantly higher scores achieved on the second comprehension performance test after watching the SQ5R video indicate that students retained more information after they used SQ5R metacognitive strategy.

As mentioned above, metacognitive activities which occurs during the self-regulated learning process is related to the time allocated to the process (Nelson & Narens, 1990). Students need to allocate more time to utilize metacognitive strategy to facilitate their reading tasks. Based on participants' eye-tracking movement behaviors combined with comprehension performance tests, this study revealed the effectiveness of incorporating metacognitive strategy SQ5R in boosting students' reading comprehension. Eye-tracking technology not only allows the researchers to capture students' visual reading process directly and precisely but also reflect the cognitive process involved in reading comprehension (Mason et al., 2015).

Implications and Recommendations

Reading is a fundamental learning skill for students in all disciplines; however, it is a necessary ability for the agricultural discipline (Gordon & Ball, 2017; Hasselquist et al., 2019; McKim et al., 2016; Park & Osborne, 2005; 2007). Agricultural educators have been called upon to promote metacognitive strategy implementation to help students become active readers (Park & Osborne, 2005; 2007). This study provides new insights into an effective metacognitive reading strategy that agricultural educators can incorporate into their classroom instruction. Specifically, using the SQ5R metacognitive reading strategy can improve agricultural students' reading skills and their comprehension of complex agricultural issues. For example, agricultural educators can develop teaching instructions which accommodate SQ5R strategy for different learning conditions, topics, and domains in the context of agriculture. Specifically, educators could implement the SQ5R strategy by leading students to survey the entire content, propose questions, and predict the meaning of key phrases. By following the SQ5R steps, students can concentrate more on the important information, which helps them gain deeper understanding of what they read and transfer the information into their memory system. Although, adopting metacognitive strategies is a self-directed action (Norman et al., 2019), it is important to increase students' motivation to use these strategies. By having a more comprehensive understanding of the metacognitive process, agricultural educators can design instructional materials to increase students' motivation to use these strategies, and ultimately improve students' reading comprehension ability.

This study is the first to utilize the eye-tracking technology to monitor and capture students' eye movement during reading processes when adopting the SQ5R metacognitive strategy. We believe eye-tracking technology is a useful tool for uncovering the complex cognitive process. In addition, this study demonstrated the implementation of eye-tracking technology in agricultural education to investigate students' cognitive process. Leggette et al. (2018) developed a conceptual framework intended to guide research using eye-tracking technology in agricultural education and communication. In the framework, they emphasized the need to investigate the effects of learning strategies on students' cognition, behavior, attention, and engagement. Therefore, the current study attempts to fill the knowledge gap by using eye-tracking technology to evaluate the metacognitive reading strategy in agricultural education.

We also acknowledge the need to continually explore metacognitive reading strategies to improve students' reading skills. Future research can examine the role and the function of each step of SQ5R and explore how it contributes to reading comprehension. In addition, future researchers should incorporate multiple analytical methods or tools to explore the underlying metacognitive process to gain a more comprehensive understanding of metacognition. For example, researchers could combine think-aloud measures with eye-tracking technology. Also, future studies can investigate the effectiveness of using SQ5R reading strategy to improve reading skills in agriscience classrooms or agricultural education professional program development. For example, future research should explore agricultural educators and students' experiences using the SQ5R metacognitive reading strategy and their attitudes and beliefs toward the adoption of metacognitive reading strategies, because these factors influence the likelihood of reading strategies being implemented in agricultural science classrooms (Hasselquist et al., 2019; Park & Osborne, 2006a).

Due to the experimental design, the study was limited to four scientific topics, and each participant was limited to two of the four scientific topics. Researchers have argued that general metacognition may be taught in different learning situations for students to transfer metacognitive skills to new learning situations (Veenman et al., 2006). Although the present study supports the effectiveness of metacognitive strategy for students' reading comprehension and knowledge retention, the sample of this study is limited to 40 participants. Thus, future studies should investigate metacognitive strategy with more participants to provide more information about the effects of metacognitive strategy on improving reading ability.

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