Journal of Agricultural Education, 59(4), 286-300
https://doi.org/10.5032/jae.2018.04286

Effects of Question Difficulty and Post-Question Wait-Time on Cognitive Engagement: A Psychophysiological Analysis

Kyle C. Gilliam[1], Matt Baker[2], John Rayfield[3], Rudy Ritz[4], & R. Glenn Cummins[5]

Abstract

Educational research surrounding teaching methods and accepted practices is continually needed to improve teaching and teacher preparation programs. The revised Bloom's Taxonomy is often used by teachers in question development. The effectiveness of these questions are often dependent, not on the question alone, but also in how the question is presented. One component of implementing effective questioning is the use of wait-time. Wait-time is the amount of time a teacher waits for a student response after having posed a question. Experts have recommended wait times ranging from three and five seconds in length. The purpose of this study was to utilize a psychophysiological measure of cognitive resource allocation (heart rate) to provide evidence of the magnitude and duration of cognitive engagement elicited after posing questions and to determine an appropriate amount of post-question wait-time needed by undergraduate agricultural education students. Study results suggest that students were cognitively engaged for two to three seconds during the wait-time that followed a question. Additionally, students re-engaged cognitively after eight seconds of wait-time. The results of this study provide unique evidence in assisting teachers with effectively employing wait-time strategies.

Keywords: Wait-time; Bloom's Taxonomy; effective questioning; cognitive resource allocation; cognitive engagement

Introduction

Educational research has been conducted for many decades to add to our body of knowledge for the improvement of teaching and learning. There is a continued need for educational research surrounding teaching methods and accepted teaching practices to improve both teaching and teacher education programs. This need is evident based on the advances in technology, especially when combined with the generational changes of students over time.

Since its development in 1956, educators have often used Bloom's Taxonomy as a resource when developing questions that require varying levels of reasoning. Bloom's Taxonomy (Bloom,

[1] Kyle C. Gilliam is an Instructor of Agricultural Education in the Department of Agricultural, Leadership, and Community Education at Virginia Tech University, 175 West Campus Dr., Blacksburg, VA, 24061, kylecgilliam@vt.edu

[2] Matt Baker is a Professor in the Department of Agricultural Education and Communications at Texas Tech University, 15th and Detroit, Lubbock, TX, 79409, matt.baker@ttu.edu

[3] John Rayfield is an Associate Professor in the Department of Agricultural Education and Communications at Texas Tech University, 15th and Detroit, Lubbock, TX, 79409, john.rayfield@ttu.edu

[4] Rudy Ritz is an Associate Professor in the Department of Agricultural Education and Communications at Texas Tech University, 15th and Detroit, Lubbock, TX, 79409, rudy.ritz@ttu.edu

[5] R. Glenn Cummins is an Associate Professor in the College of Media and Communications at Texas Tech University, 2500 Broadway, Lubbock, TX, 79409, glenn.cummins@ttu.edu

Englehart, Furst, Hill, & Krathwohl, 1956) originally consisted of six hierarchical levels of cognitive engagement ranging from knowledge to evaluation. In 2001, Anderson and Krathwohl reviewed and revised Bloom's original Taxonomy by using action verbs to label each level of the Taxonomy and by switching the evaluation and creating levels, making creating the highest level in the Taxonomy.

Higher-level thinking skills have often been reported as important for an individual's education, as well as an important engagement technique for teachers (Whittington & Bowman, 1994: Torres & Cano, 1995; Geertson, 2003; Christopher, Thomas, & Tallent-Runnels, 2004; Ulmer & Torres, 2007; Clark & Paulsen, 2016; Ganapathy, Singh, Kaur, & Kit, 2017). While researching the cognitive discourse of professors, researchers found that although professors wanted to teach at all cognitive levels, their discourse tended to be in the lower levels of cognition (Whittington, 1995; Ewing & Whittington, 2009).

In addition to developing higher-level thinking skills, educators are often encouraged to employ post question wait-time (Rowe, 1969; Rowe, 1974; Shrum, 1984; Tobin, 1987; Tincani & Crozier, 2008). Rowe (1974) defined wait-time as the amount of time a teacher waits for a student response after having posed a question, and she suggested that three to five seconds was an adequate amount of time to wait for a student response. However, Burden and Byrd (1999) suggested three seconds is not enough time for a student to process and respond to a question, and thus recommend waiting at least five seconds before soliciting a response. Borich (2014) suggested that a wait-time that is too short or too long could be detrimental and posited that a wait-time that was too long would waste valuable instructional time. For this reason, Borich (2014) suggested a wait-time of at least three seconds. However, he also noted that more divergent questions might require much longer wait times. In light of these recommendations, it stands to reason that students may need longer to process information for more difficult, higher-levels of questioning and could possibly need less time to process information for less difficult, lower levels of questioning. In fact, Gage and Berliner (1998) suggested that teachers provide three to four seconds of wait-time for lower level questions and up to 15 seconds of wait-time for higher-level questions.

Psychophysiological measures of cognitive resource allocation provide a novel means of examining this question. Although this approach has not been used in this context, Fischer et al.(2018) used psychophysiological assessment to measure cognitive resource allocation to determine that science-based messages better engage beginning farmers and livestock producers than testimonial-based video messages. Additionally, Fox et al. (2004) used heart rate data to determine the effects of graphics used in television news on the cognitive engagement of both younger and older viewers. Utilizing these tools provides a look into the cognitive processes and emotions that occur during exposure to each level of question and provides evidence of overall duration and intensity of cognitive engagement when students are allowed "post question wait time" to process and formulate answers.

Theoretical Framework

The use of psychophysiological measures of cognitive processing rest upon an information processing theoretical framework. Information processing is a theory commonly used in education to explain how an individual receives, stores, and uses information. Cognitive psychology often compares the mind to a computer, suggesting that humans are information processors. According to information processing theory, the human mind processes information by encoding data, storing the encoded data, and then retrieving the stored data when needed. Encoding is "the selection of incoming information for further processing, resulting in a short-term, working memory pattern of the neuronal activation that represents the selected information" (Potter & Bolls, 2012, p. 71).

Storage refers to the creation of a new neuronal network that can be activated through retrieval (Potter & Bolls, 2012). Retrieval is more clearly explained as the activation of the neuronal networks that have been developed from previous exposure to selected information (Potter & Bolls, 2012). All three components of information processing happen simultaneously, allowing for the encoding, storage, and retrieval of information to concurrently be utilized by the information processor.

As a measurement paradigm, psychophysiology refers to the connection between the psychological and physiological responses an individual has to a stimulus. Bioelectrical signals are sent throughout the body by nerve cells within the central nervous system and the peripheral nervous system (Potter & Bolls, 2012). These nerve cells contribute to either the sensory system or the motor system, meaning nerve cells either provide information to our brain based on our senses, or are used to activate muscles such as skeletal muscles, organs, and glands (Potter & Bolls, 2012). The nerves that control organs and glands are known as the autonomic nervous system and is of primary importance to psychophysiological measures (Potter & Bolls, 2012). The automatic nervous system is composed of the sympathetic nervous system and the parasympathetic nervous system (Potter & Bolls, 2012). Most organs and glands are dually innervated, meaning that they are constantly receiving signals from both the sympathetic nervous system and parasympathetic nervous system (Potter & Bolls, 2012). Activation of the sympathetic nervous system is tied to arousal, while activation of the parasympathetic nervous system is tied to the allocation of cognitive resources (Potter & Bolls, 2012).

Cognitive resource allocation can be measured through the activation of the parasympathetic nervous system. Researchers have linked the activation of the parasympathetic nervous system to cognition by means of the deceleration of heart rate, meaning that as resources are allocated to cognition an individual's heart will slow down (Potter & Bolls, 2012). This cardiac deceleration increases the quality of sensory inputs being received by an individual during encoding (Graham, 1979). This decrease in heart rate is the physiological response that occurs in conjunction with the psychological response of cognitively processing information, thus making heart rate a reliable indicator of cognitive resource allocation and the intake of potentially significant information (De Pascalis, Barry, & Sparita, 1995).

Cognitive resource allocation takes place through both controlled processing and automatic processing, with both being equally important in how attention is allocated by an individual. Controlled processing refers to an individual's conscious effort to allocate cognitive resources based on that person's interests and goals (Lang, 2009) and is generally tonic in nature, meaning that it lasts over a longer period of time (Potter & Bolls, 2012). In contrast, automatic processing is generally elicited through an orienting response to an element of a message. An orienting response is also referred to as the "what is it" response to novel information in one's environment (Potter & Bolls, 2012). Automatic processing is referred to as a phasic response, meaning it is a shorter, temporary response to a stimulus (Potter & Bolls, 2012).

Purpose and Research Questions

This study supports Research Priority four – meaningful, engaged learning in all environments, of the American Association for Agricultural Education Research Agenda (Roberts, Harder, & Brashears, 2016). The purpose of this study was to provide evidence of the amount and duration of cognitive engagement elicited after posing questions and to determine an appropriate amount of post-question wait-time needed by undergraduate agricultural education students. The following research questions were used to address this purpose:

RQ_1: Is there a significant effect of question difficulty on cognitive resource allocation over five seconds of post question wait-time of Agricultural Education teacher certification students?

RQ_2: Is there a significant effect of question difficulty on cognitive resource allocation over 10 seconds of post question wait-time of Agricultural Education teacher certification students?

Methods

Population

The population for this study was undergraduate students completing teacher certification requirements in Agricultural Education at Texas Tech University. A convenience sample consisted of 40 students who volunteered from the Department of Agricultural Education and Communications, who were currently enrolled as agricultural science teacher certification students. Fraenkel, Wallen, and Hyun (2015) recommend a minimum of 30 subjects when conducting experimental and quasi-experimental research, and the present study employed a within-subject experimental design to preserve statistical power. Subjects were paid $20 for their participation in the study as an incentive. One subject was removed from the study due to an unreadable data set. Of the remaining 39 subjects, 27 were female and 12 were male. The subjects were primarily upperclassmen (n = 35) with a mean age of 21.21 (SD = 1.96). The mean GPA for the sample was 3.30 (SD = .43) on a 4.0 scale. These student attributes are similar to those reported by Morales Vanegas (2015) and Carraway (2015).

Design

According to Campbell and Stanley, (1963) an equivalent time samples design was utilized. In summarizing this design, they state that: "this is a recurrent design in physiological research, in which a stimulus is repeatedly applied to one animal, with care taken to avoid any periodicity in the stimulation, the latter feature corresponding to the randomization requirements for occasions demanded by the logic of the design" (Campbell & Stanley, 1963, p. 45). Each subject received all combinations of each treatment condition (Keppel & Wickens, 2004, Ary, Jacobs, Sorenson Irvine, & Walker, 2019) for this study. The first design was a 2 (question difficulty) x 2 (question repetition) x 5 (seconds in time) within-subject design. The second design was a 2 (question difficulty) x 10 (seconds in time) within-subject design.

Treatment Stimulus

The treatment stimuli consisted of five video lessons over characteristics of effective teachers. The first video presented an introduction to Rosenshine and Furst (1971), while the other four videos addressed the effective teacher characteristics of clarity, variability, enthusiasm, and task-oriented and business-like behavior. At the end of each video, a question was asked by placing the question on the screen.

Following each question, the subjects were given either five or 10 seconds (post question wait time) to process and formulate a response. Subjects were not informed on the amount of time provided to process and formulate a response to the question. At the end of the post question wait-time, directions were presented on the screen instructing the subjects to deliver their response to the posed question by recording their answer in a pen and paper questionnaire packet. To control for the possible impact of order effects, a counterbalanced design was employed such that two different presentation orders of the stimulus videos were created (Keppel & Wickens, 2004; Fraenkel, et al., 2015).

Independent Variables

Question difficulty. Bloom's Taxonomy consists of six hierarchical levels of questioning and thinking. The six levels from lowest order to highest order are Remembering, Understanding, Applying, Analyzing, Evaluating, and Creating (Anderson & Krathwohl, 2001). Bloom's Taxonomy provides a framework for developing questions that provide an increasing level of difficulty. Question difficulty for this study was operationalized as low- and high-level of difficulty. Four questions were generated from the remember and understand (low difficulty) levels of Bloom's Taxonomy (Anderson & Krathwohl, 2001) with two questions being written for the clarity video and two questions being written for the enthusiasm video. Four more questions were generated from the evaluate and create (high difficulty) levels of Bloom's Taxonomy (Anderson & Krathwohl, 2001), with two questions being written for the variability video and two questions being written for the task-oriented and business-like behavior video. All eight questions were approved by a panel of experts on Bloom's Taxonomy from various universities across the U.S (Ary et al., 2019). Researchers were considered experts on Bloom's Taxonomy if they had published at least three studies utilizing Bloom's Taxonomy. The panel received an instrument with all eight questions listed, and were asked to rate each question as a high- or low-level question based on their knowledge of the revised Bloom's Taxonomy (Anderson & Krathwohl, 2001). All eight questions received a unanimous rating from the panel of experts. From these eight questions, one question was selected for each video to be included in the study for a total of four questions. The low-level questions used in the study were: 1. Give an example of how a classroom teacher could exhibit clarity while teaching. 2. List three ways discussed in this lesson that can be used to exhibit enthusiasm. The high-level questions used in the study were: 1. Critique this lesson on variability. How might you improve the variability in this lesson. 2. Explain why or why not task-oriented and business-like behavior is important for a teacher.

Post-question wait-time. Wait-time was defined as "the pause following any teacher utterance and preceding any student utterance" (Tobin, 1987, p. 90). Wait-time for this study consisted of two levels (five seconds and 10 seconds). At the completion of posing each question, a black screen was produced that lasted the duration of the wait-time, five seconds for the first level and 10 seconds for the second level of wait time. This was done to prevent measuring cognitive resource allocation dedicated to re-reading the question as opposed to processing the question after presentation.

Dependent Variables

Cognitive resource allocation. Cognitive resource allocation was used to determine the effectiveness of level of question difficulty and post question wait time on agricultural education undergraduate students. Cognitive resource allocation was operationalized through heart rate deceleration over time, as a decrease in heart rate is a physiological indicator for cognitive processing. Heart rate was collected during message viewing through the use of an electrocardiogram (ECG) that records the electrical signals produced by the heartbeat. ECG was collected by placing electrodes on the forearms and the non-dominant wrist of the subject (Potter & Bolls, 2012). The ECG collected the time between R spikes of the QRS complex and was displayed as an ECG waveform. The QRS complex is the portion of the ECG waveform denoted by negative and positive deflections. The first negative deflection is the Q wave and the first positive deflection is the R Spike (Ashley & Niebauer, 2004). The second negative deflection is the S wave.

The ECG data were transformed into the more common heart rate data of beats per minute (BPM). Furthermore, a baseline dataset was collected by averaging the heart rate data collected in the five seconds prior to exposure of the stimulus (Potter & Bolls, 2012). This baseline data was subtracted from each one second time period of heartrate data collected during exposure to the stimulus to create a change score used for analysis (Potter & Bolls, 2012). Change scores are used to minimize the difference in the various resting heart rates of the subjects. As the baseline heart rate is subtracted from the heart rate data collected during stimulus exposure, a decrease in heart rate will be indicated by a negative heart rate change score.

Cognitive resource allocation was analyzed by extracting data from the five and 10 second time segments corresponding to each post question wait time. The BioPac system used to collect the psychophysiology data recorded 1,000 measurements per second (Potter & Bolls, 2012). For this reason, the psychophysiology data were resampled offline into one-second segments for the ease of data analysis. One second segments were deemed adequate as this study explores the trends of cognitive resource allocation, operationalized as heart rate change, over five and 10 seconds.

Procedures

Subjects selected for the study were required to come to the psychophysiology research laboratory located in the Center for Communication Research at Texas Tech University. Prior to arrival of the subjects, electrodes were prepared for use to minimize the amount of time a subject had to wait prior to beginning the study. Disposable electrodes were used for the collection of heart rate data. Disposable electrodes can be prepared in advance and are easier to place than non-disposable electrodes, making them more efficient. Electrodes for heart rate require the addition of an electrolyte gel to increase conductivity of the electrode and provide a clearer signal for data collection (Potter & Bolls, 2012).

Upon arrival of the subjects, they were asked to complete a demographics questionnaire to record subject gender, age, and student classification. Once the questionnaire was completed, the subjects were seated in a reclining chair situated approximately four feet away from a flat-panel television. They were asked to turn off their cell phone to eliminate the risk of outside interference. Each subject's skin was cleaned and prepped prior to the attachment of the electrodes (Potter & Bolls, 2012). An alcohol swab was used to clean the skin where the ECG electrodes were placed. Heart rate data were collected by placing a ground source electrode on the non-dominant wrist of the subject and by placing an electrode 2-inches below the elbow crease on both forearms (Potter & Bolls, 2012).

Subjects were instructed to remain as still as possible during exposure to the stimulus to reduce movement artifact that can distort the collected signals (Potter & Bolls, 2012). The lights were lowered, and the door was shut prior to the beginning of the experiment. Subjects then viewed instructions on the screen and a 20 second period was utilized prior to the viewing of the first video to allow the subjects to become comfortable and their physiological responses to return to a normal state.

Each subject was randomly exposed to one of the two orders of the treatment videos. After exposure to the stimulus, the researcher removed all the electrodes and provided paper towels to wipe off any gel left on the skin from the electrode placement.

Data Analysis

For the five-second wait-time trials, a 2 x 5 factorial repeated-measures ANOVA was utilized to test research question one to determine the differences between low- and high-level difficulty of questions over five seconds of wait-time, and the interaction effect of question difficulty and time for cognitive resource allocation. For the 10-second wait-time trials, a 2 x 10 factorial repeated-measures ANOVA was utilized to test research question two to determine the differences between low- and high-level difficulty of questions over 10 seconds of wait-time, and the interaction effect of question difficulty and time for cognitive resource allocation. This design allowed the researcher to test for a main effect for level of question difficulty, a main effect for time (five seconds or 10 seconds), and an interaction effect between level of question difficulty and time for cognitive resource allocation for both research questions.

The research questions were tested with the alpha level for significance set *a priori* at p = .10. This is an acceptable level of risk, as this research utilizes new research tools and begins to explore cognitive resource allocation in a new setting (Gall, Gall, & Borg, 2007). Mauchly's test was used to test the assumption of sphericity (Field, 2018). Potter and Bolls (2012), indicate that psychophysiology research often does not meet the assumption of sphericity and thus recommends using the Greenhouse-Geisser estimate to correct the F-ratio. According to Stevens (2002), multivariate procedures are more powerful than univariate procedures when there is a large violation of sphericity and a sample size larger than ten subjects. P-values provide limited information and cannot determine the size of an effect (Wasserstein & Lazar, 2016) and appropriate effect sizes should be calculated for each analysis (Keppel & Wickens, 2004). Effect sizes are used to determine the size of the effect. Keppel and Wickens (2004) suggested using partial omega squared to calculate effect size. Effect sizes for this study were interpreted based on the recommendations of Keppel and Wickens (2004).

In their discussion of experimental research, Ary, et al., (2019) acknowledged the paradox between strongly controlled internal validity and its artificiality and external validity. They remind their readers that internal validity must be established and verifiable prior to concerning themselves with external validity. This study had tightly controlled internal validity, which indeed limits its external validity. In their classic publication on experimental design, Campbell and Stanley (1963) state "both types of criteria are obviously important, even though they are frequently at odds in that features increasing one may jeopardize the other" (p.5).

Results

Research Question One

Table 1 shows the means and standard deviations for heart rate on two levels of question difficulty and the five testing times. Mean scores for heart rate change in response to low-level questions decreased through the first three seconds, and increased back towards the baseline over seconds four and five (see Figure 1). Mean scores for heart rate on high-level question difficulty were slightly lower than the mean scores for heart rate on low-level question difficulty, but display a similar pattern by exhibiting a decrease through the first three seconds, before beginning to rise back towards the baseline score over seconds four and five.

Table 1

Means and Standard Deviations for Change in Heart Rate on Two Levels of Question Difficulty and Five Testing Time Intervals (n=39)

	Low-Level		High-Level	
Testing Time	M	SD	M	SD
Second 1	-2.28	6.00	-2.78	6.39
Second 2	-2.63	7.24	-3.04	6.22
Second 3	-2.67	6.31	-3.34	6.73
Second 4	-1.79	5.72	-2.87	6.34
Second 5	-1.36	6.69	-2.08	6.30

Note. A negative mean score indicates a decrease in heart rate from the baseline score

Table 2

Repeated Measures ANOVA for Question Difficulty and Time Over Five Seconds

	SS	*df*	*MS*	*F*	*p*	ω_p^2
Question Difficulty						
Within groups	90.04	1.00	90.04	.927	.342	>.001
Error	3689.40	38.00	97.09			
Time*						
Within groups	156.85	2.51	62.40	2.944	.046	.047
Error	2024.51	95.52	21.20			
Question Difficulty X Time**						
Within groups	10.18	2.02	5.04	.138	.873	>.001
Error	2806.13	76.81	36.53			

*Greenhouse-Geisser ε= .628, Mauchly's W= .122, $\chi^2(9)$ =76.744, $p < .001$

**Greenhouse-Geisser ε= .505, Mauchly's W= .093, $\chi^2(9)$ =86.395, $p < .001$

Table 2 shows the results of the repeated-measures ANOVA for question difficulty and time over five seconds for cognitive resource allocation. Sphericity was not violated for the main effect of question difficulty as there was only two levels. Mauchly's test indicated that the assumption of sphericity had been violated for the main effect of time, $\chi^2(9) = 76.74$, $p < .001$, and the interaction effect of question difficulty and time, $\chi^2(9) = 86.40$, $p < .001$. Therefore, degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity (ε= .628 for the main effect of time and .505 for the interaction effect of question difficulty and time).

For the five-second wait-time trials, there was no main effect of question difficulty on cognitive resource allocation, $F(1.00, 38.00) = .927$, $p = .342$, $\omega_p^2 > .001$. There was a significant main effect of time on cognitive resource allocation, $F(2.514, 95.516) = 2.944$, $p = .046$, $\omega_p^2 = .047$. The pairwise comparisons for the main effect of time revealed the mean difference of -1.285 between time interval at three seconds and five seconds was significant at the .1 level ($p = .095$). There was no interaction between question difficulty and time on cognitive resource allocation, $F(2.021, 76.809) = .138$, $p = .873$, $\omega_p^2 >.001$.

Figure 1 shows the estimated marginal means for heart rate by question difficulty over five seconds. For both question difficulty levels, heart rate declines over the first three seconds, before beginning to increase over seconds four and five.

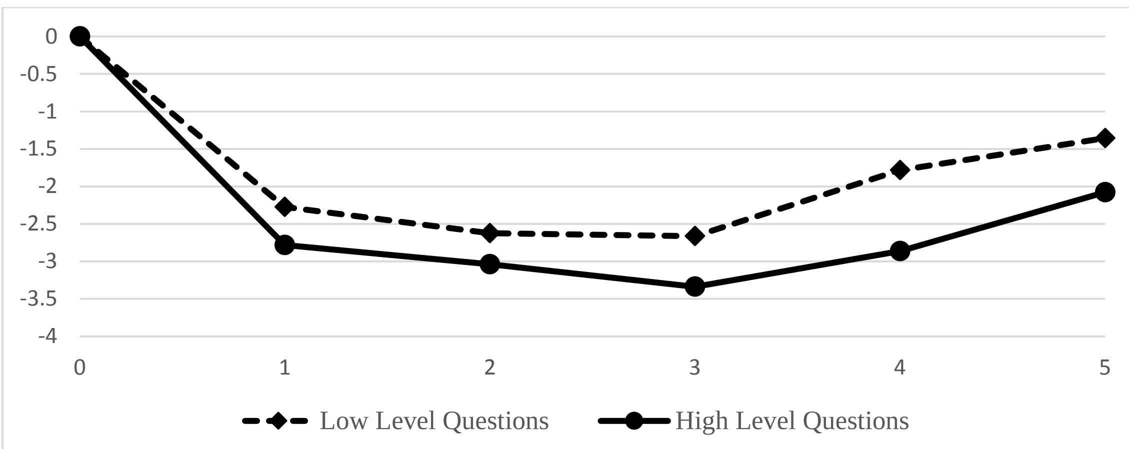

Figure 1. Estimated marginal means of heart rate change scores for question difficulty over five seconds, indicating a drop in heart rate during the first three seconds of wait-time.

Research Question Two

Table 3 shows the means and standard deviations for heart rate on the four questions and the 10 testing times. Mean scores for heart rate on low-level question difficulty show a decrease over the first two seconds. Seconds three through five show the mean scores rising back towards the baseline score, before decreasing again over second six, and stabilizing through seconds seven and eight. In addition, the mean scores for low-level question difficulty show a decrease over seconds nine and ten. Mean scores for heart rate on high-level question difficulty show a considerable decrease over the first two seconds, followed a gradual rise back towards the baseline score. Similarly to the low-level question difficulty mean scores, the high-level difficulty mean scores revealed a substantial decrease over seconds nine and 10.

Table 3

Means and Standard Deviations for Heart Rate Change Scores on Two Questions and Ten Testing Times (n=39)

	Low-Level		High-Level	
Testing Time	M	SD	M	SD
Time 1	-1.64	4.49	-4.82	8.77
Time 2	-1.67	6.61	-5.16	8.31
Time 3	-1.23	5.24	-4.71	6.65
Time 4	-.79	4.56	-3.91	6.49
Time 5	-.28	4.68	-2.87	6.97
Time 6	-1.30	3.91	-2.95	6.29
Time 7	-1.26	5.42	-2.69	5.65
Time 8	-1.01	6.62	-1.88	6.45
Time 9	-2.52	6.21	-3.59	7.07
Time 10	-3.77	5.88	-4.98	5.64

Note. A negative mean score indicates a decrease in heart rate from the baseline score

Table 4

Repeated Measures ANOVA for Question Difficulty and Time Over 10 Seconds.

	SS	*df*	*MS*	*F*	*p*	ω_p^2
Question Difficulty						
Within groups	486.70	1.00	486.70	2.56	.126	.069
Error	3609.39	19.00	189.97			
Time*						
Within groups	304.21	3.37	90.35	2.01	.115	.047
Error	2881.51	63.97	45.04			
Question Difficulty X Time**						
Within groups	101.63	3.33	30.50	.56	.657	>.001
Error	3412.56	63.31	53.91			

*Greenhouse-Geisser ε= .374, Mauchly's W= .000, $\chi^2(44)$ =165.281, p < .001

**Greenhouse-Geisser ε= .370, Mauchly's W= .000, $\chi^2(44)$ =135.008, p < .001

Table 4 shows the results of the repeated-measures ANOVA for question difficulty and time over 10 seconds for cognitive resource allocation. Sphericity was not violated for the main effect of question difficulty as there was only two levels. Mauchly's test indicated that the assumption of sphericity had been violated for the main effect of time, $\chi^2(44) = 165.28$, $p < .001$, and the interaction effect of question difficulty and time, $\chi^2(44) = 135.01$, $p < .001$. Therefore, degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = .374$ for the main effect of time and .370 for the interaction effect of question difficulty and time).

For the 10-second wait-time trials, there was no main effect of question difficulty on cognitive resource allocation, $F(1.00, 19.00) = 2.56$, $p = .126$, $\omega_p^2 = .069$. There was no main effect of time on cognitive resource allocation. However, the main effect of time approached significance, $F(3.37, 63.97) = 2.01$, $p = .115$, $\omega_p^2 = .047$. There was no interaction effect between the question difficulty and time on cognitive resource allocation, $F(3.33, 63.31) = .57$, $p = .66$, $\omega_p^2 > .001$.

Figure 2 shows a graph of the estimated marginal means of heart rate for question difficulty over 10 seconds. The graph shows a decline in heart rate for both levels of question difficulty over the first two seconds, followed by a steady increase in heart rate through second five. The low-level question difficulty sees a sudden drop at second six, followed by a steep drop in heart rate after second eight. The high-level question continues a steady climb after second five, then drops suddenly after second eight.

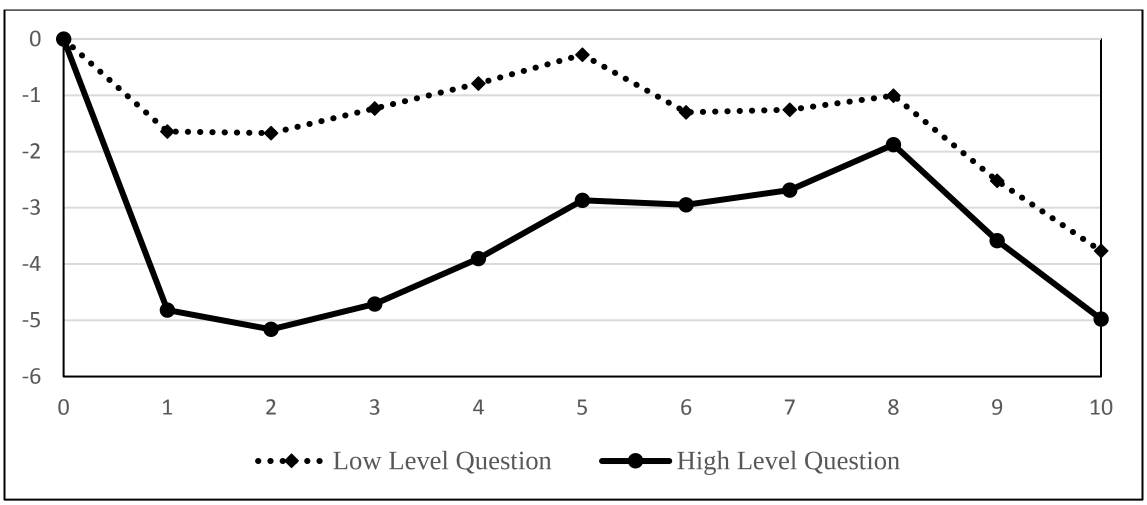

Figure 2. Estimated marginal means of heart rate change scores for question difficulty over ten seconds.

Conclusions and Recommendations

The amount of cognitive resource allocation was assessed based on the theory of information processing for two levels of question difficulty (low-level and high-level) over time (five seconds and 10 seconds) following the solicitation of the question. Bloom's Taxonomy (Bloom, et al., 1956) and the revised Bloom's Taxonomy (Anderson & Krathwohl, 2001) suggest there is a difference in the amount of cognitive processing that takes place in low-level and high-level questions. This study found no statistical difference between the two levels. However, for both research questions the graphs of estimated marginal means showed a larger decrease in heart rate for high-level versus low-level questions. Likewise, there was a medium effect size (ω_p^2 = .069) for question difficulty for the second research question. This suggests that, on average, high-level questions elicited slightly deeper cognitive processing than low-level questions.

When examining the amount of cognitive processing over time, research question one found a significant difference between second three and second five. There was a small effect size (ω_p^2 = .047) for time for research question one. The visual inspection of the graph indicates the subjects were primarily engaged cognitively for both low-level and high-level questions through the first three seconds of the post-question wait-time. This suggests that after the first three seconds, subjects had processed the question and developed an answer. This supports the suggested amount of wait-time provided by Rowe (1974) of three to five seconds.

The second research question was approaching significance on question difficulty and time. There was a small effect size for time (ω_p^2 = .047) for research question two. The visual inspection of the graph revealed an initial similar pattern of cognitive engagement to that found in research question one. However, this initial cognitive engagement only lasted two seconds, rather than three, suggesting that the subjects processed the question and their response within those first two seconds before becoming cognitively disengaged. However, there was a trend for both low-level and high-level questions that indicated the subjects re-engaged with cognitive processing after eight seconds. This could be an indication that the subjects were beginning to reconsider their initial thought process, which would in part support the suggestions of Borich (2014) and Gage and Berliner (1998). However, Borich (2014) and Gage and Berliner (1998) only suggested longer wait-times for higher level or more divergent questions. The results of this study suggest that students may take advantage of longer wait-times for both high- and low-level questions.

Based on the results of this study, it is recommended that teachers utilize a wait-time of at least three seconds when asking a question regardless of the difficulty of that question. This will provide at least enough time for students to process and formulate a response. However, it may be beneficial to employ longer wait-times if a student does not provide an initial response to the question within the first five seconds.

Further research should be conducted to explore the cognitive engagement of students over a 15 second period of wait-time and address the specific thought process of the student to determine if the cognitive engagement in longer periods of wait-time are focused primarily on processing and answering the posed question. Additional studies should also be conducted to explore the best practices for teachers during extended wait-times where students fail to respond to the initial question, as well as how to proceed when students provide an incorrect or insufficient response to the initial question.

Piaget's (1972) stages of cognitive development and Perry's (1999) forms of intellectual development, suggest that individuals continue to rapidly form and develop their cognitive and intellectual abilities from teen years through their early twenties. This constant change in cognitive abilities might suggest that younger, high school aged subjects could have an entirely different cognitive response during post-question wait-time. Since this study was conducted with undergraduate students with a mean age of 21.21 years and who were primarily enrolled in upper-level courses, it is recommended that further research be conducted with high school aged subjects.

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