

## Examinations of Cognitive Processing of Science Writing Tasks

Richard L. Lamb<sup>1</sup>  
Brian Hand<sup>2</sup> and  
Sae Yeol Yoon<sup>2</sup>

### Abstract

**Context:** The current nature of educational research in the discipline of science limits the application of outcomes that can be reached in terms of empirical evidence that supports emerging theory.

**Objective:** Much of the work in science education at all levels is focused on trying to gather evidence to better understand how student learning occurs within the science classroom.

**Methods:** The authors make use of functional near infrared spectroscopy, a non-invasive neuroimaging technique to examine outcomes related to authentic educational tasks.

**Results:** A main effect of writing condition and phase in summary writing and argumentative writing respectively was found.

**Conclusions:** The results of this initial study do highlight the value of using neuroscience to help build understanding of the cognitive processes associated with writing in science. Importantly, the use of the fNIR does provide evidence about the relative strength of processing required in undertaking these different writing tasks.

**One sentence summary:** In this study we demonstrated the ability to distinguish between writing types in science using optical imaging techniques.

**Keywords:** Cognition; Science writing; Education

- 1 Department of Learning and Instruction, Hall Amherst, NY, USA
- 2 Department of Teaching and Learning, Hall Amherst, NY, USA

**Corresponding author:** Richard L. Lamb

✉ rllamb@buffalo.edu

Department of Learning and Instruction,  
Hall Amherst, NY, USA.

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### Introduction

As neuroscience and neuropsychology gain attention in the wider popular imagination, one has to ask about the impact and influence of these domains on fields such as education and specifically science education. Many educators argue that the foundational partner in education is cognitive psychology or perhaps social psychology, however we posit a blending of cognitive psychology and neuroscience would provide greater utility for research and understanding human learning and that education is one of the largest untapped areas of research in neuroscience. This is because ultimately all educational research is constrained by the lack of understanding of structure and function of the human brain. Despite this obvious link between neuroscience, neuropsychology, and education, there is considerable consternation in education as to the practical application of these fields to educational practice. Educational academics claim there are disconnects between education and

neuroscience at a fundamental level. As such research in science education has yet to take advantage of basic research offered by these fields; instead wanting to focus on applied research. This purpose of this article is to provide an example of how this bridging between disciplines (neuroscience/neuropsychology and education) can occur.

Much of the work in science education at all levels is focused on trying to gather evidence to better understand how student learning occurs within the science classroom. However, the current nature of educational research in the discipline of science limits the application of outcomes that can be reached in terms of empirical evidence that supports emerging theory. In essence there is considerable theory development without adequate theory testing. For example, of the 54 research articles published in the last year, in the top rated science education journal, 78% were self-report, with 67% of the articles qualitative in nature. This provides evidence that self-report is the dominate

form of data collection in science education. Most studies draw conclusions from self-report, surveys, and interviews and thus are not able to comment on the wider theoretical underpinnings in an effort to test or build theory in science education. This is because unfortunately, self-report measures of this nature are consistently shown to be unreliable in assessing the impact of learning in science [1,2]. More importantly these studies leave educators with even fewer insights about what actually works in the science classroom for teachers on a level of scale above the individual. One potential solution to this problem is to establish deeper connections between basic and applied research in the science of learning where the focus of such programs of research is on establishing empirical outcomes in understanding student learning and learning processes. By implementing such cross-disciplinary research, we believe that we can move away from only examining student outcomes on behavioral tasks, such as a test, and to begin to examine student cognitive processing and tools used to achieve performance on such tasks. While researchers in science education conceptually engage with the idea of learning being both a process and product, current research approaches do not enable a rich understanding of the process to be obtained. The overlap between science education and neuroscience is an attempt to merge product and process to help develop a deep understanding of learning. As it stands now science educators can only speculate about the processes which explain the product.

### Educational neuroscience and neuropsychology

The emerging field of Educational Neuroscience brings together members of multiple communities who are interested in exploring and understanding how learning and education occur in the science classroom. The measurement of specific cognitive dynamics in individual students is critical for understanding the role of cognition and brain function as it relates to the process of learning in the science classroom. Functional near Infrared Spectroscopy (fNIR) is a portable non-invasive imaging tool capable of being used at the student level to understand the hemodynamic responses i.e. broad level cognitive processing of students in the natural classroom setting. While equipment such as Functional Magnetic Resonance Imaging (fMRI) devices have been widely adopted in the Neurosciences since its invention in the 1990s, education has been slow to adopt this equipment for reasons such as cost, lack of expertise, lack of recognition of the potential use of these tools to clarify questions and test hypotheses in science education and thus impact educational decisions by the teacher in the science classroom. By having an affordable and manageable method to examine cognitive processing, the fNIR does provide a pathway for educators to characterize the complexity of learning that occur in science classrooms [3]. An example of the application of this technology is in the understanding of the role of writing in the science classroom.

### Writing in the science classroom

Current research into the role of writing as a learning tool within science classrooms has provided evidence that significant

advantages are gained by students with respect to conceptual understanding of a topic [4]. Research is also beginning to focus on the cognitive engagement required by students to be successful [5] and the variation in cognitive demand that different types of writing place on writers in science [6]. In parallel to the rise of writing in science, the Next Generation Science Standards requirements have increased the focus by teachers on understanding cognitive processes in science as students engage in science learning [7]. To better understand these successes in writing and the demands of the NGSS means there is a need to study the use of the cognitive processes that are necessary to enable students to have success in learning science. A specific question which has yet to be answered which is different in processing required and used as students undertake different writing tasks that occur within science classrooms. The focus of this study was to begin to address this question through the use of neuroimaging techniques. The writing tasks presented in this study are real tasks used in science classrooms which enabled the researchers to use the fNIR to examine cognitive processes for realistic classroom tasks. Specifically, examining the cognitive dynamics of students as they engaged in these different writing tasks in science allows science educators to not only examine the products of learning such as the resultant written responses but also the processes of learning occurring in real-time as the student engages in the writing process. The examination of the combination of the process of learning with the fNIR and the written sample as products of learning provide greater depth of understanding and confirmation of suspected underlying theorized relationships between types of writing and learning in science. This need to understand the underlying relationships coupled with an increase demand for implementation of the Next Generation Science Standards has created this need to examine and triangulate claims around the levels of cognitive demand.

Two types of writing that are now being emphasized within the Next Generation Science Standards are argumentative and summary writing. Argumentative writing is where students are asked to generate an argument where questions, claims and evidence are cohesively connected to explain the outcomes of an inquiry. Summary writing is writing that summarizes the conceptual ideas that have been addressed within a unit of work and are written to audiences other than the teacher. For example, a college student may be asked to write an explanation of some science process to a grade school student. Research into these different types of writing has argued that these two different types of writing place different cognitive demands on the writer. Importantly, empirical evidence from young writers has shown that shifting the type of writing task and audience that young authors write to, has benefits in terms of performance on end of unit tests [8]. Importantly recent work by [9] has shown that summary writing has a greater impact on critical thinking skills than argumentative writing as measured by the Cornell Critical Thinking test. However, while these results indicate differences in cognitive activity when completing the writing tasks, there is currently existed scientific empirical evidence in support of these claims.

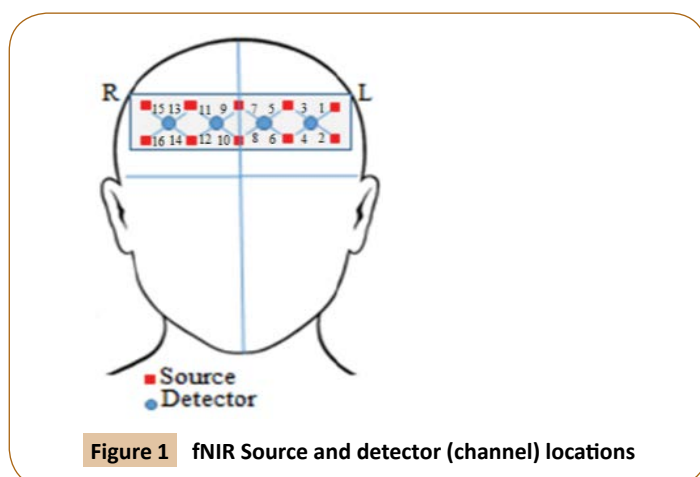
While there has been research on the use of these writing types over the last two decades this research has focused on the conditions needed for success in writing in science, the tasks demands that are part of the writing process, and the success of using writing to learn approaches in terms of student performance in science. Repeatedly studies have shown a consistent pattern of significant advantage for students in science using approaches such as writing. While a number of studies have engaged in examining the cognitive processing used within the act of writing, this work has engaged in such research by looking at the product of the writing and deconstructing of the text. However, because of the nature of this type of research, an understanding of the actual real-time cognitive dynamics occurring during the text construction has not been able to be achieved.

## Methods

In order to examine the cognitive dynamics associated with these two different forms of writing, we recruited 100 college aged participants and identified localized hemodynamic activations in the prefrontal cortex using fNIRs as they engaged in undertaking these two writing tasks. The total number of students is appropriate as per a priori power analysis. Power analysis suggests that there is a .95 probability for detection of small effect using 98 participants. The estimation of small effects is derived from prior studies [10]. The fine temporal resolution of the fNIR enabled us to obtain valuable continuous information on the fluctuations and disruptions in cognitive processing via the localization of oxygenated and deoxygenated hemoglobin as the neurons in the brain metabolize glucose due to task engagement [11]. The use of the fNIR allowed examination of the temporal changes in hemoglobin oxygenation that reflect increased mental activity in the frontal lobe. Location of particular interest are in the areas of optodes 1 through 4 see **Figure 1**. These areas have been specifically implicated in processing related to critical thinking, memory, and attention processing in prior studies. Locations of additional interest are optodes 13 through 16 Optodes 13 through 16 as these have been implicated in phonological orthographic processing.

### Characterizing the complex responses

The researchers made use of hemodynamic measures using



**Figure 1** fNIR Source and detector (channel) locations

fNIR to topographically characterize the complex responses in the frontal cortex areas of the brain during the two forms of writing in science. Hemodynamic responses were examined using a sampling rate of 2 Hz and triangulated with student writing outcomes. In addition to oxygenation and deoxygenation of hemoglobin we examined the resultant cognitive dynamics associated with each writing prompt response. In this study, we demonstrated the ability to distinguish between writing types in science using optical imaging techniques. We compared the relative cognitive demand for the summary and argumentative writing tasks, finding that the summary writing task was characterized by greater intensity of activation with a larger number of activation sites.

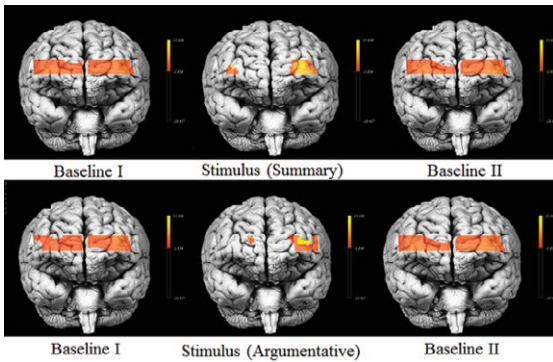
Written and oral informed consent was obtained from each study participants and the study protocol conforms to the ethical guidelines of the "World Medical Association Declaration of Helsinki - Ethical Principles for Medical Research Involving Human Subjects" adopted by the 18th WMA General Assembly, Helsinki, Finland, June 1964 and amended by the 59th WMA General Assembly, Seoul, South Korea, October 2008, as reflected in a priori approval by the appropriate institutional review committee.

## Statistics and Results

Statistical analysis was carried out through examination of hemodynamic response related to condition type i.e. summary and argumentative writing and phase i.e. Baseline I, Stimulus, Baseline II. A main effect of writing condition and phase in summary writing and argumentative writing respectively was found ( $F(5, 94)=3.32, p=.008$ ). The summary writing ( $M=3.483, I=1.05$ ) activation in the Optodes locations 1 and 3 and Optodes locations 13 and 14 regions than the argumentative writing ( $M=2.12, SD=1.88$ ). In addition, there appears to be a greater number of locations activated during the summary writing task. **Figure 2** provides a visualization of the areas of activation. Figures on the left are illustrations of baseline and figures on the right illustrate activations above baseline.

A more global view of the fNIR results are illustrated in **Figure 3**. The graph also shows the timing between Baseline I, Stimulus, and Baseline II. Visual examination of the graph illustrates significant activation as a time of 300s followed by maintenance of the of the elevated response. Post stimulus the activation decreases back toward baseline but does not completely return to baseline. Both graphs exhibit similar over all patterns, however the hemodynamic response is followed by a sharper decline in summary writing when compared to the decline shown in argumentative writing. It should be noted that the intensity of the response is greater for summary writing indicating the students had greater relative cognitive demand.

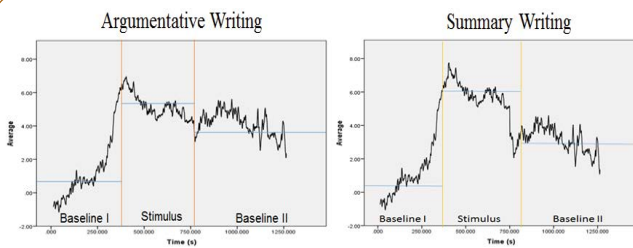
A correlational analysis was conducted to examine the relationship between activation locations and writing type (summary and argumentative). Correlational analysis reveals that there are significant relationships between summary and argumentative writing and location controlling for reading ability ( $r_{P2W.RA}=.56, p<.001, \text{Moderate}$ ).



**Figure 2** Imaging illustrating activations between summary writing tasks and argumentative writing tasks in science.

## Discussion

The results of this initial study do highlight the value of using neuroscience to help build understanding of the cognitive processes associated with writing. Importantly, the use of the fNIR does provide evidence about the relative strength of processing required in undertaking these different writing tasks. Linking this type of data with that from more traditional education type analyses of student writing will enable the development of richer understanding of the underlying processes used matched to performance outcomes from the products put forward by the students. As such this will enable theoretical understandings to be developed that have the potential to impact learning in science classrooms.



**Figure 3** Mean graph of Baseline I, Stimulus, and Baseline II, for channels showing statistically significant differences.

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