ARTICLE

Eye Tracking and Learning Predictability

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ARTICLE INFO	ABSTRACT

Eye-tracking is a unique research method in education to help understand learners' attention to learning materials, reading struggles, learning strategies, and learning behaviors within the context of multimedia. This study overviews the empirical studies in this field, examines the role of eye-tracking in learning predictability, and discusses the ways that eye-tracking can be used for early intervention..

1. Introduction

Education in the 21st century is marked by the rapid development and deployment of technology applications in the classroom. In an era of Digital Natives, where more than fifty-eight percent of children between ages two to five are able to play a computer game and more toddlers can open a web-browser than can swim independently, there is a requisite that instruction consist of meaningful technology integration. Within the learning environment this integration should be seamless and fluid, not exacting attention drawn to the tools, regardless of their type (tablet, smartboard, mobile devices, etc.). This is essential to the contribution of learning and developing student proficiencies (Lai, 2011).[18] While technology has provided options to differentiate instruction, engage and address diverse learners, its uses as a predictor of student learning needs and archetype for developing individualized learning plans has been limited. Research seeking to address and inform the existing body of work is being conducted by using eye-tracking. Eye-tracking studies are not new, but new applications are offering findings that have the potential to improve students' learning outcomes.

Eye-tracking research has been conducted to determine language development (Valleau, Konishi, Golinkoff, Hirsh-Pasek, & Arunachalam, 2018),[30] recognition of types of documents, the need for reading remediation (Sibert, Gokturk & Lavine, 2000),[26] and impact of multimedia learning (Alemdag & Cagiltay, 2018).[1] Central to the studies conducted is the ability to use eye-tracking as a predictor of recognition, ability, and processing. While research inclusive of the K-12 environment has been limited, the results have yielded positive outcomes, offering potential for expanded

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opportunities applicable to primary and secondary education environments. Existing research lends to the potential to improve students' abilities to engage with complex text, construct new meaning, and produce work reflecting levels of growth and mastery. The results could have profound implications for closing achievement gaps and addressing questions regarding equity and college-career ready curriculum (Catrysse, Gijbels, Donche, DeMayer, Lesterhuis, & Van de Bossche, 2017).[7]

The role of technology and multimedia instruction is continuously expanding, shaping student learning. Given the implications of one-to-one initiatives, the rapid development and deployment of multimedia platforms, and online statewide assessments, insight into how students process text and the ability to identify academic struggles early are an imperative. Understanding how eye-tracking contributes to these foci offers increased opportunities to improve instructional outcomes, as defined by indices of student engagement and proficiency. The purpose of this study is to explore two questions: (1) Can eye-tracking be used as an early determinant of cognitive abilities? (2) What role can eye-tracking assume in identifying students' learning needs, such as remediation and/or evaluation?

2. Eye-Tracking: Definition and Function

According to Lai et al. (2013),[19] eye-tracking provides a method to determine what features are being attended to and for how long a subject is attending to a specific feature. Through eye-tracking it has been determined how attention is shifted (Hyönä, 2010),[15] enabling researchers to deduce the level of interest displayed by a subject (Duchowski, 2003).[9] A chief concern of parents and teachers is that students often struggle to "focus," preventing them from gaining the necessary understanding and ability to perform tasks (Taylor & Nutta, 2014).[27] Eye-tracking can record what items an individual has focused on and the length of that focus. Understanding the association of how eye movement and the creation of mental images are linked enable researchers and educators to use these measures to determine cognitive capacity and the need for intervention strategies (Lai et al., 2013).[19]

Central to understanding how eye-tracking is measured involves a series of fixations and saccades. Fixation represents the ability to maintain a visual gaze on an isolated location; a saccade denotes the conjugate movement of both eyes between phases of fixation (Purves et al., 2001).[22] As attention is focused the eye maintains position (fixed), and as the individual tries to process or becomes frustrated the eyes will fluctuate (saccade), looking to other images. These patterns have been linked to further tests in recall and processing that aid researchers in determining whether participants understand and how their under-

standing can be linked to developing skills or providing intervention.

Fixation has been studied in three scales: total fixation duration, average fixation, and time to first fixation (Alemdag & Cagiltay, 2018).[1] Total duration represents the overall length of time to which one will attend on any one specific item or item set. Average fixation is the mathematical function of how long we attend within a specified time, incorporating the number of times we fluctuate or saccade to other items within that same amount of time. Finally, time to first fixation accounts for the period when an individual first becomes "fixed." For example, in a study of infant noun vocabulary, infants as young as 22 months when presented with two images would take an initial look at one move to the other and so on, before he/she would maintain attention on one image longer than the other, thereby, fixating or choosing one image on which to attend (Valleau et al, 2018).[30] The time that lapses between the saccades before becoming fixed is known as time to first fixation. According to Russo and Rosen (1975),[24] eye-fixations are a reliable measure because they are "unobtrusive, detailed, and difficult to misrepresent" (p. 272). Combined with the quick changes, saccades, studies have been able to link attention, interest, and understanding. These factors resulted in a positive correlation between eye-movements and cognitive processing (Lai et al. 2013).[19]

How we "attend" to images and texts holds relevance in educational practices by marking interest, time on task, and in the expression of understanding skills and content, factors that are directly correlated to processing and ability to recall and add meaning to what is being taught (Alemdag & Cagiltay, 2018; Valleau, Konishi, Golinkoff, Hirsh-Pasek, & Arunachalam, 2018).[1][30] Though the current research is limited with the K-12 community, the existing research offers relevant results as it pertains to understanding the questions presented for further study of eye-tracking within this environment.

3. Existing Research

Eye-tracking has been used for more than one hundred years. In 1879, ophthalmologist Luis Émile Javal first observed that readers used both short fixations and quick movements while engaging with text (Eyesee, 2014).[10] According to Eyesee (2014),[10] continued studies led to the development of the first eye-tracker built by Edmund Huey, and even though the device was cumbersome to use it enabled research to be conducted yielding results that were the first findings on eye-tracking research, published in the *Psychology and Pedagogy of Reading*. The publication provided a clear indication of both the need and application of eye-tracking in understanding how the mind

processes information, contributes to the acquisition of knowledge, and influences the individual. The results substantiate that there is potential for pedagogical practices.

Since the publishing of the initial eye-tracking results, studies have been conducted using eye-tracking in business (e.g., developing marketing campaigns), and in education (e.g., with those physically immobile). Each application has drawn on the concept of attracting and maintaining the attention to sway towards a desired end, be it buying cigarettes, defining an intervention, or operating a wheelchair. How then can a continued and expanded use of eye-tracking research improve instructional outcomes? There must be a review of current usage and applications and their success with an understanding of how those findings lend to expanding research that can be generalizable to current considerations. For the purposes of this study, that would mean determining the ability for early identification of cognitive struggles and/or the need to develop instructional interventions that will yield the greatest impact on improved student outcomes within a specified time period. What succeeds is a review of studies that include language acquisition, marketing, diagnosing dyslexia, development of interventions and tutoring tools, cognition, and online assessments. Each study provides data demonstrating the need to understand attention and academic struggle. Collectively, these studies offer support for the use of eye-tracking research to be applied in the education setting with the belief that results will lead to identification, early intervention, and increased levels of student achievement.

Valleau et al, (2018)[30] conducted a study that focused on language acquisition and development. Language acquisition studies have focused on vocabulary development as determined by a child's ability to recognize nouns. The researchers in this study shifted the focus from the use of noun to verb recognition as a means of understanding developing vocabulary. The study used images to determine if the participants, through monitoring of fixations and saccades, recognized specific actions, i.e., clapping verses stretching. The pictures used in this study contained both static images and those in which motions were mimicked, for example, hand clapping were depicted to determine if verb recognition was present in toddlers. The results show that as early as 22 months old, eye-tracking revealed receptive knowledge of verbs, providing the researchers with a positive correlate in understanding the development of vocabulary in toddlers. This ground-breaking addition, in an area that has long focused only on using nouns as an index of vocabulary can now be broadened to include the recognition of verbs in understanding vocabulary development and their role in expressive and receptive language.

As previously mentioned, attention is central to cognitive processing. If one cannot maintain the attention necessary, and is without academic support, the task to be mastered is met with frustration (Moore & Wilcox, 2006).[21] In my educational experiences in and out of the classroom, attention problems are correlated to a lack of proficiency and behavior problems as those students who are unable to attend to a topic for a designated period of time are more likely to engage in off-task and/or risk behaviors that result in removal from the instructional environment (Freeman, Simonsen, McCoach, Sugai, & Lombardi, 2015).[11] In a culture of high stakes testing, where rigor is a reflection of school performance scores and teacher effectiveness is a direct correlate to students' abilities to perform on assessments, behavior becomes both critical and central to ensuring success. Understanding attention is an inherent factor to learning (Duchowski, 2003).[9] Eye-tracking has presented the opportunity to identify and determine at what point and how long an individual gives attention to a specific target. Fixations and saccades provide descriptive analytics regarding when and the amount of time the individual gives attention to the targeted stimulus, whether an image or text.

Eye-tracking has also been used to identify academic struggles. Rello and Ballesteros (2015)[23] used eye-tracking to determine if readers had dyslexia, the most common neurological learning disability that impacts language processing. The key to supporting those with dyslexia is connected to the initial diagnoses of the disability. In this particular study, using eye-tracking the researchers were able to use text presentation and text readability to identify those individuals who presented difficulty in recognizing and/or decoding text. Further, the use of eye-tracking proved to be less intrusive as it provided for reading in silence. The findings of their work note a difference in eye movements of readers with and without dyslexia and indicate the potential for using eye-tracking as a means of diagnosing the disability. Kunze, Utsumi, Ishimaru, and Kise (2013)[17] sought to examine how eye-tracking could record and quantify reading habits, noting specifically how individuals moved through text, recording fixations and saccades as they pertained to preferences and time to move from one section to another. The researchers determined that eye-movement also revealed frustration levels in readers, offering data that could identify interventions that would support learning needs (Huettig & Brouwer, 2015).[14] In another study, Anderson and Gluck (2001)[3] applied eye-tracking to determine if an instructional advantage could be produced

by tracking eye-movement in students who were being tutored in algebra. Anderson, Douglass, and Qin (2013) [2] used the results in their eye-tracking study to develop interventions to improve performance on algebraic tasks. Similarly, Kaufman, Klein, Koblitz, and Price (2018) [16] applied eye-tracking to tobacco regulatory science to examine communication and marketing and the impact on consumers, using sales data to determine usefulness of the strategy.

Academic struggles are compounded when there are skills deficits – the result of cognitive anomalies (i.e., learning disabilities) or the result of ineffective instructional practices. Existing research regarding eye-tracking studies has produced results that validate the prediction of abilities and deficits. Coupled with research focused on the impact of early intervention's role in improving student outcomes, eye tracking could offer a method whereby students who struggle could be identified earlier and intervention offered before deficits widen (Sansosti & Morris, 2017). [25] The result would offer teachers and administrators an opportunity to see the direct results of the current year's instruction reflected in the VAM Model (Hermann, Walsh, & Isenberg, 2016). [13]

With applications across various disciplines, eye-tracking research offers education the significance of understanding how we attend to information. Combined with identifying academic struggles, such as in the role of diagnosing dyslexia, eye-tracking methodology produces data useful to the educational evaluation process that results in the identification and development of instructional support plans for students in the form of individualized accommodation plans (IAPs) and individualized educational plans (IEPs). These studies present collective findings that are directly related to student learning and instructional outcomes, offering a relevant link between eye-tracking research and the K-12 education community.

4. Cognitive Abilities: What and How We learn

Determining cognitive abilities begins at birth, monitoring developmental milestones, and continues throughout our formal education. The point at which a learning deficit is identified offers increased optimization of interventions (Baker, McIntyre, Blacher, Crnic, Edelbrock, & Low, 2003). [5] Cognition is the process by which new knowledge is acquired and calls for consideration of individual abilities and needs (Butz, 2004). [6] Early identification of academic struggles provides a window of time, that with the appropriate interventions could promote successful compensation skills or even allow the student to "catch up," essentially performing in accordance with development models of their same age peers.

Programs such as Head Start are ideologically intended to provide learners with an opportunity to begin their formal schooling earlier than statutes require (Moore & Wilcox, 2006). [21] Baker et al, (2003) [5] note that participation in early academic experiences provide learners with exposure to structured content intended to support their readiness. Accompanying this early learning is the opportunity to identify potential academic challenges. The sooner a classroom teacher is made aware of or identify a struggle, the sooner he/she can begin providing and documenting interventions, noting what worked and what produced no outcome. If educators are to bear the responsibility of academic increase, they must have the ability to recognize and provide interventions, while receiving additional supports for those students for whom interventions have stalled progress. To the extent eye-tracking can provide insight into academic struggles early, it would be a welcomed method for data gathering as an assessment protocol.

Presently eye-tracking research has been conducted in the areas of reading, mathematics, multimedia, speech, and learning strategies. Understanding the ability to learn and how learning is constructed is central to the education profession. There are measures such as Intelligent Quotient (IQ) protocols and learning evaluations (conducted as components of special education programs); however, these usually warrant the ability to perform certain tasks. As mentioned earlier, eye-tracking has been conducted on toddlers, yielding evidence specific to attention, knowledge acquisition, and vocabulary development (Valleau et al, 2018). [30]

Early identification of cognitive capabilities offers opportunities to inform best practices in education. Best practices shape professional practice, a key component in developing pre-service and in-service education professionals. The extent to which professional practice is improved is directly connected to the opportunity to identify student struggles and address learning needs. As a building level administrator, I have seen students become frustrated with what they define as their lack of intellect or inability, when in most instances their current struggle is the result of an unidentified cognitive issue, which having had the proper identification would have led to interventions, many of which would support the experience of academic success. This reality is not the assignment of blame, nor is it the resignation of responsibility as an educator, merely an immutable fact to which the extent we are able to isolate academic struggles early provides the potential for positive outcomes. The

expansion of eye-tracking as an assessment tool offers the K-12 education community venues to early intervening strategies to support knowledge acquisition and success, the basis for Multi-Tiered Systems of Support (MTSS).

Multi-Tiered Systems of Support (MTSS)

Academics and behaviors are inextricably linked, with both serving as indicators of instructional effectiveness and student proficiency (Arden, Gandhi, Edmonds, & Danielson, 2017).[4] The Multi-Tiered Systems of Support (MTSS), as noted in Figure 1.1, provides an effective framework for identifying antecedents, defining intervention strategies, and rewarding growth (Freeman et al, 2015).[11] Formerly known as Response to Intervention (RtI), the framework provides a tiered approach for instructional planning and behavioral modifications. The base of the framework, known as Tier I represents the "core" or 80% of students within schools and the instruction and behavior support attributing to their success. Tier 2 represents those students in need of "targeted" interventions and behavior modification planning. Educators refer to this as "small group" instruction, usually in a 1:5 or 1:8 ratio of teacher to student. This tier represents 15% of students within the school. Finally, Tier III, denotes "intensive" interventions, representing only 5% of students and to the extent possible providing 1:1 supports.
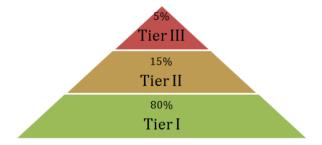

Figure 1.1 Multi-Tiered System of Supports

Multi-Tiered Systems of Support was defined as the requisite to conducting special educaiton evaluations (Arden, Gandhi, Edmonds, & Danielson, 2017).[4] Areas of concern, academic or behavioral, are identified and students are referred for interventions. Based on premliminary data points, including questionaires, parent interviews, and testing data, targeted skills are identified. The significance of understanding the model is tied to the procedural requirements within the OSEP provisions; evaluation must proceed placement. The framework provides a model focused on consistent interventions with the intention to prevent disproportionate identification of students (Cowen Institute, 2014).[8] Because Multi-Tiered Systems of Support requires interventions to be

documented and provided over a specified time period before students can be moved from one tier to another (Appendix 1), eye-tracking can be used to serve as an evaluation component, providing data points that serve in place- or time-bound interventions. As noted in multiple studies, eye-tracking has provided information that informs recognition, patterns, and processing. As in the case of those with dyslexia, if eye-tracking results demonstrate lack of recognition, frustration, or the inability to process text early in the learning continuum, these data could replace the six-week period required to determine intervention.

Studies have garnerd supporting results that affirm eye-tracking's ability to identify deficits and inform learning strategies (Lai et al., 2013;[19] Rello & Ballestreros, 2015;[23] Sibert, Gokturk, & Lavine, 2000).[26] Additional studies inclusive of K-12 education, focused on attention, interventions, processing, reading and math difficulties have potential to provide time saving measures to reduce the amount of time given to providing interventions and when students should enter the evaluaion process for either the development of an Individualized Accommodation Plan (IAP), under Section 504 of the Americans with Disabilities Act or services defined by an Individualized Educational Plan (IEP) (Arden, Gandhi, Edmonds, & Danielson, 2017).[4] Each plan requires supporting data, which can include fixations and saccades, time to first fixation, and first saccade or the inability to fixate as done in eye-tracking data.

Data regarding recognition, processing, and point of frustration are important to identifying the appropriate tier and corresponding interventions. Using eye-tracking in this way serves as an assessment protocol that under Child Find provisions, informs both school readiness and the need for instructional support. With the development and adoption of Common Core State Standards and increased proficiency demands of statewide assessments, readiness requirements for students entering kindergarten have increased, for example, the introduction of algebraic concepts, increased reading (both in volume and complexity of texts), and the expanded requirements for writing in all content-based assessments (Engligh, math, science, and social studies) (Taylor, Watson, & Nutta, 2014).[27]

According to Toch and Tyre (2010),[28] these changes are focused on having learners demonstrate less the regergitation of content and more the analysis and evaluation of the content to enable the explanation of problem solving. For example, math students no longer have to solve the problem showing work; they must now identify the answer and justify the steps taken leading to

the selection of the response. In English, multiple texts are to be analyzed and used to develop a composition, citing evidence from each. In social studies, students need not recall dates and events; they must analyze primary and seondary sources, establish a claim (position) and develop an expository essay citing evidence from the sources to support the claim. While assessments still require knowledge of the content areas, the determinant of proficiency is attributed to the problem-solving and evidence used to reach conclusions. This revision in testing policy is very demading on student time and attention. In test items released by the Louisiana Department of Education,the social studies assessment included four sources, a combination of texts, maps, and images and required both selected responses and an extendend response (essay), all to be completed within 75 minutes (LDoE, 2019). [20]

Eye Tracking as Intervention

Determining which interventions are to be used and the effectiveness of said interventions can present obstacles. Based on the MTSS model, interventions must be provided consistently for a approximately six weeks, using a continued progression based on student mastery and improvement. Given the importance of time in determining the effectiveness of an intervention and the role of intervention in the evaluation process, the extent to which a targeted discriminant intervention can be applied yields more presciptive academic supports (Sibert , Gokturk, & Lavine, 2000).[26] Fixations and saccades allow a pattern to unfold providing information that correlates to attention and understanding (Valleau, Konishi, Golinkoff, Hirsh-Pasek, & Arunachalam, 2018).[30] According to Sibert, Gokturk, and Lavine (2000),[26] their study which involved adult readers, shows that fixations and saccades occur in a pattern. Fixations were held as a variable that measured the number and duration, and the specific location (in this case line of text) of the eye (gaze) at a given moment. Saccades were studied for the number of and size (average saccade includes 7-9 characters), determined by the repetitive back and forth movement of eye. The regression of saccades (noted by a size of only 3-4 letters) indicated text that presented difficulty to the reader. Similarly duration of fixation can also be correlated to difficulty comprehending text. McConkie and Zola (as cited by Sibert, Gokturk, & Lavine, 2000)[26] determined that eye movement offers understanding in the nature of cognitive processes, particular those involved in reading. In a similar study, Anderson, Douglass, and Qin (2013)[2] determined that eye-tracking, specifically the role of fixations and saccades, revealed their role in brain-mapping activity involved with solving mathematical

equations.The results of their study indicated that the resulting brain pattern imaging and problem solving provided evidence of imaging contributing to improved instruction in math. Collectively, evidence from these studies provides information critical to the understanding the role of eye-tracking and how it can support the identification of academic interventions. Expansion of studies involving students, particularly in the K-12 environment, has the potential to inform the intervention process, noting specifically text that presents difficulty. Of particular significance is identifying early literacy skills.

The work conducted by Greenwood, Carta, Godstein, Kaminski, McConnell, and Atwater (2014)[12] dentotes a prevalence in students who struggle with reading, noting that by grade three, one in three students demonstrates deficits. These deficits are connected to the opportunities to which those who have been impacted had opportunities involving home-based language and literacy exposure and their participation in pre-school programs, with more than forty-percent of students unable to reach levels of reacing proficiency by fourth grade (Greenwood, Carta, Goldstein, Kaminski, McConnell, & Atwater, 2014).[12] Efforts to provide instructional support occur infrequently leading to a widening in the gap of age appropriate skill proficiency. To address this, the use of defined MTSS interventions at the universal (Tier I), small group (Tier II), and intensive/individualized (Tier III) levels were identified and teachers engaged in professional development as an impetus to effective implementation of the defined strategies. Results substaniated a need for differentiated levels of instructional support as currently defined with the MTSS framework.

Reading has not been the only application for eye-tracking studies. Andrà, Arzarello, Ferrara, Homqvist, Lindström, Robutti, and Sabena (Tzekaki, Sakonidis, 2009)[29] found that students with different background knowledge engage mathematical texts in different ways. Given math often involves visual representation, i.e., formulas, graphs, and words, attempts to make meaning from each involves the employment of various skills. Students present with different competencies in mathematics making it difficult to support how each individual may decode the meanings of mathematical representations (Tzekaki & Sakonidis, 2009).[29] Andrà et al. (as noted in Tzekaki & Sakonidis, 2009)[29] divided participants into two groups in the study, based on levels of understanding, being either beginning or advanced. Using a combination of motion graphs and geometry, fixation data supported the inference that beginners and experienced math students have significantly different cognitive processes. Those with more expertise

demonstrated fixations that indicated he/she imagines elements that are not represented in the image, enabling a more involved process to solve problems; whereas, beginners demonstrated a pattern of eye moves that alternated more, allowing the researchers to infer that the task presented more of a struggle.

As an early intervening approach, MTSS provides students with a more explicit, intensive, and personal instructional plan (Greenwood, Carta, Goldstein, Kaminski, McConnell, & Atwater (2014).[12] To the extent eye-tracking studies are conducted beginning at age two, there is potential to identify cognitive deficits, build language, discriminate mathematical representations, and provide interventions to minimize and/or prevent pervasive academic struggling (Catrysse, Gijbels, Donche, De Maeyer, Lesterhuis, & Van den Bossche, 2017;[7] Valleau, Konishi, Golinkoff, Hirsh-Pasek, & Arunachalam, 2018).[30]

5. Conclusion

Eye-tracking research has been conducted in various fields with the goal to understand how learners pay attention to the multimedia information and how their attention impacts learning. The extant research studies on eye-tracking in K-12 education have revealed that determining academic struggles at an early age would lead to interventions that could improve academic success. This study points out a promising direction for future research on learning predictability, early intervention, and student success.

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