NEUROCOGNITIVE PROCESSES IN CHILDREN DURING TALK IN THE CLASSROOM

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1. Introduction

1.a. Talk in the classroom

One of the most prominent methods of communication in the classroom is verbal language. Accordingly, talk is an everyday occurrence in elementary classrooms between students and teachers. Talk is used in the classroom by teachers as a teaching strategy to relay information for student learning. On a typical school day, you will commonly see teachers communicate with students through talk during whole-group lessons, small instructional groups, and practice activities. Through this form of communication (talk), teachers engage students in learning by activating background knowledge (i.e., decoding information from long-term memory to working memory), scaffolding new information for encoding into long-term memory, and expanding semantic and procedural networks (Lamb et al., 2021). In addition, other forms of talk exhibited in the classroom include student-to-student and student-to-group talk, which more closely involve communication between students without a prevalent teacher role. Some specific talk-based teaching strategies that are used in modern elementary classrooms include grand conversations and number talks. Grand conversations, used in language arts instruction, involve the teacher facilitating interactions among students as they discuss language arts topics typically involving literature (Tompkins, 2014). All students are encouraged to participate in the discussion by listening to others talk and responding to classmates with their own opinion in reference to literature (Tompkins, 2014). Thus, students are actively involved in cognitive processes when participating in grand conversations. This is demonstrated by students' ability to form strong arguments and contribute to the discussion. Number talks, used in mathematics instruction, are led by the teacher, and aim to engage students in meaningful discussions regarding math concepts (May, 2020). Number talks involve purposeful talk moves performed by the teacher to guide students to make new meaningful connections and understandings of math concepts (May, 2020). In both teaching strategies, students are expected to engage in talk with classmates and the teacher to create a discussion and build new understanding. Thus, the two strategies exemplify how talk and communication in the classroom is used to advance student learning by engaging in cognitive processes, such as cognitive resource recruitment and expanding semantic and procedural networks.

The use of talk and the act of learning from others, specifically between individuals with distinct levels of acquired knowledge (e.g., teacher vs. student), is related to Lev Vygotsky's (1962) sociocultural theory of cognitive development and Zone of Proximal Development (ZPD) (Gauvain, 2008). Vygotsky's sociocultural theory recognizes social interactions between people and the social environment as a crucial role in the cognitive development of children particularly during key developmental periods (Gauvain, 2008). Sociocultural theory also emphasizes the role of a more knowledgeable or experienced individual assisting others through collaborative communication (e.g., ZPDs) (Gauvain, 2008). Zone of proximal development involves identifying a student's current understanding to expand upon the student's level of knowledge (Gauvain, 2008). This is done by scaffolding student's learning and providing instruction that targets their zone of proximal development (Gauvain, 2008). In turn, Vygotsky's sociocultural theory and ZPD have influenced many pedagogies in education, such as Dialogic Teaching (Reznitskaya, 2012). Dialogic teaching is a teaching pedagogy that promotes the engagement of students in discussions involving higher order thinking to promote their construction of meaning (Reznitskaya, 2012). Dialogic teaching advocates for student-led discussions in which students collaboratively take control of the conversation, such as deciding the questions being discussed or the flow of the conversation (Reznitskaya, 2012). This pedagogy ties to sociocultural views since it emphasizes the crucial role of talk and the social environment in student's learning.

The effectiveness of talk in the classroom as a learning strategy has been repeatedly tested by educators and researchers through trial and error, observation, case studies, etc. (e.g., Atwood et al., 2010; Dikker et al., 2017; Lamb et al., 2021; Reznitskaya, 2012). Specifically, Lamb et al. (2021) has found that "the relationship between the student and teacher develops as they engage in talk and this strong relationship is indicative why talk is central to science education and education in general" (p. 25). Thus, it is apparent that talk is crucial to the learning process and in the development of cognition in children.

1.b. Brain neural coupling

Current research in cognitive neuroscience has considered the underlying neurocognitive mechanisms occurring during talk in classroom settings. More specifically, brain coupling has been shown to have potential as a reference system for understanding students' behaviors during learning in the classroom by linking neuroscience to educational behaviors (Lamb et al., 2021). Brain neural coupling is the time-locked moment where a speaker's talk results in activity in the listener' brain. (Lamb et al., 2021). This time-locked synchronization of brain activity occurs only when the listener understands the speaker's talk and is not present when there is no understanding (Lamb et al., 2021). Due to this neurological process, the synchronization of brain activity between the speaker and listener (i.e., brain neural coupling) is a fundamental marker of the process of learning in addition to serving as a representation of mutual understanding and comprehension.

Findings in cognitive neuroscience regarding the process of brain neural coupling, which is prominent during talk among students, can function as a beneficial tool in education towards predicting student learning outcomes. For instance, a notable finding by Dikker et al. (2017) demonstrates how the intensity of brain coupling between two people can be used to predict student class engagement and social dynamics in a classroom. Moreover, results from brain neural coupling may also give insight into student preference towards different teaching strategies. For example, in a high school classroom, Dikker et al. (2021) found that the intensity of brain synchronization increased when students participated in lessons involving videos and group discussion; the students in this classroom preferred discussion and videos over other activities they participated in.

As aforementioned, sociocultural theory of cognitive development highlights learning through social interactions such as talk. In addition, sociocultural theory provides behavioral markers which can be used to identify underlying cognitive processes occurring during talk, Process 1 and Process 2 (Lamb et al., 2021). Process 1 being the externalization of talk by the speaker (i.e., teacher) and the listening by the listener (i.e., student) (Lamb et al., 2021). Process 2 refers to the internalization of the speaker's talk by the listener and the act of building understanding through brain processes (Lamb et al., 2021). Internalization consists of using semantic and procedural networks, and engaging in cognitive system clustering, and cognitive resource recruitment (Lamb et al., 2021). In other words, a student assimilates new information that they learned through talk into existing networks of knowledge and retrieves information from long-term memory to working memory. Accordingly, Process 2 can be used to identify significant individual differences that are present when brain neural coupling occurs due to existing semantic and procedural network differences among individuals. Furthermore, brain neural coupling is not a single mechanism, but rather shows underlying neurocognitive mechanisms occurring in individuals during talk (Dikker et al., 2017). Thus, it is necessary to consider Process 2 (i.e., internalization) to gain a better understanding of student learning and how brain neural coupling occurs among diverse individuals.

1.c. Purpose & research questions

Two significant studies regarding brain neural coupling direct interests towards the importance of individual differences in neurocognition (Dikker et al., 2017; Lamb et al., 2021). These individual differences in neurocognition are important as they affect individual students' learning outcome; they affect what a student can recall from a lesson or learning activity. Individual differences include personality traits, attention, background knowledge, and overall patterns in neurocognitive responses that relate to semantic and procedural networks (Dikker et al., 2017; Lamb et al., 2021). Consequently, talk between a speaker and listener can be interpreted in various ways by different listeners and lead to diverse learning outcomes.

This research study will further examine how individual differences in neurocognitive processes give rise to distinctions in learning and comprehension through talk in the classroom. This study examines neurocognitive processes occurring in elementary students as they engage in talk-based learning activities. The research aims to answer the following questions:

- How do individual differences impact brain neural coupling during classroom talk?
- How can brain neural coupling effectively be used to improve current or introduce new teaching strategies or pedagogies?
- How can brain neural coupling be applied to differentiated instruction or accommodations in the classroom for specified student populations?

We hypothesize brain neural coupling between the teacher and student will occur when the student reaches an understanding of what the teacher is communicating. It is expected that the locations of activation in the speaker's brain will be predictive of areas activated in the listener during neural coupling. These areas of interest being the prefrontal and parietal lobes which are associated with memory, interpretation of language, decision-making, etc. (Lamb et al., 2021). It is hypothesized that there will be significant differences in individual learning outcomes when students engage in talk in the classroom and when neural coupling is present versus not present. These differences may include existing semantic and procedural networks, background knowledge, personal interests, or teaching style preferences. We hypothesize that the identified individual differences in neurocognitive processes that occur as children engage in talk will aid in answering research question 2 and 3. We predict results will suggest that brain neural coupling has potential to be used as a reference system to assess student learning outcomes and thus support results from past studies (Dikker et al., 2017; Lamb et al., 2021).

1.d. Functional near-infrared spectrometer (fNIRS)

This study will utilize a functional near-infrared spectrometer (fNIRS) to analyze quantitative data of brain activity occurring during brain neural coupling between a speaker and listener. fNIRS is a neuroimaging tool that examines hemodynamic responses which are related to oxygenation and deoxygenation of hemoglobin due to neurocognitive activity (Lamb et al., 2021). As the brain functions, there is a hemodynamic response that is tied to neurocognitive activity at a specific time and location in the brain. Therefore, fNIRS can be utilized to identify specific time-locked responses which indicate that neural coupling has occurred between a speaker and listener's brain (Lamb et al., 2021). In turn, neural coupling is a predictable, time-locked response that will occur when understanding is reached during talk. fNIRS captures similar information found in functional magnetic resonance (fMRI) but is more convenient for use in classroom settings (Lamb et al., 2021). fNIRS bands are noninvasive as it is placed on each participants' head and allows for hemodynamic responses to be recorded during talk in natural or semi-naturalistic classroom settings (Lamb et al., 2021). On the contrary, fMRI is difficult to use in classroom settings as it is limited to use in the laboratory. This is crucial to this study due to the set purpose and research questions we aim to answer; the questions consider how findings from cognitive neuroscience can be used in real classroom settings. By using a noninvasive form of data collection, results of the study will more accurately reflect children's neurocognitive processes naturally occurring during talk in the elementary classroom. Consequently, findings can be translated into classroom practices (e.g., pedagogies and teaching strategies) that teachers can more realistically implement in their instruction.

2. Materials and Methods

2.a. Participants

This study is an observational stimulus-response study taking place in a semi-naturalistic classroom setting. A total of 32 participants were involved in this study. Participants included teachers and students sampled from the participating teachers' classes. All participants were from the same school district in the Northeastern and Mid-Atlantic regions of the United States. Participants consisted of 16 fourth grade students ranging the ages of 10-11 years and 16 teachers ranging the ages of 23-26 years. Students and teachers were randomly assigned into pairs to make 16 teacher-student dyads. The dyads purposefully excluded the pairing of students to their own classroom teacher to mitigate unaccounted factors between the preexisting teacher-student relationships. As the dyads engage in conversation, neuroimaging data will be collected using fNIRS as well as documentation of student learning through content assessment strategies such as questionnaires and content tests.

2.b. Procedures & conditions

The procedures abided by the ethical standards provided by the Institutional Research Committee in addition to the 1964 Helsinki Declaration. The participants or guardians gave informed consent prior to participating in the study. Procedures and conditions used in this study were modeled after the 2021 study by Lamb et al. Participants were placed in university laboratory classrooms for 65 minutes. Only one dyad was present in a classroom setting at a given time to eliminate interference of conversations between other dyads. An fNIRS band was placed on each participants' head. For 5 minutes, Baseline neuroimaging data was collected before (Baseline I) and after (Baseline II) the completion of each classroom task. For those 5 minutes, the students' eyes remained closed and there was no interaction between the teacher and student. Baseline I and Baseline II serve as the neural rest condition in which no stimulus is presented to the dyads.

Each dyad participated in individual talk sessions to engage in 5 total tasks: 4 distinct talk-based tasks and 1 task of listening to white noise. The four talk-based activities varied in levels of complexity including language complexity and form of media (e.g., text and recording). The ordering of conditions was the following:

1. Fourth Grade Science Task
2. College Science Task
3. Fourth Grade Non-Science Task
4. White Noise Task
5. Recorded Fourth Grade Science Task

The first task incorporated a text excerpt from a fourth-grade science textbook, *Inspired Science,* published by McGraw Hill. The second task incorporated a summary text of a college geology textbook excerpt. The third task incorporated a summary of a non-science fourth grade text, *The Hope Chest*. For each task, the teacher did not read the text prior to beginning the task. During the task, the teacher read the text aloud to the student. During the fourth task, the participants listened to white noise to serve as a control condition. The fifth task incorporated a recorded summary text from a different fourth-grade science textbook. The recording was played aloud for the student and teacher. Each of the tasks took approximately 6 minutes to complete. During each task, the participants' hemodynamic responses were monitored until their responses returned to Baseline. Upon the completion of each activity, the participants' understanding of the content was assessed through oral questionnaires and/or content tests. For all 5 tasks, participants were asked about their understanding of the content and to rate their understanding on a scale of 1 to 4 (1 = none of the text, 2 = some of the text; 3= most of the text; 4= all the text). Based on the content discussed in the fourth-grade science (Task 1), college science (Task 2), nonscience readings (Task 3), and recorded fourth-grade science text (Task 5), students also completed a 5-question multiple-choice test to measure their level of understanding for each of the texts.

2.c. Data

For all tasks, the fNIRS band collected hemodynamic response data for 54-optodes significant to brain neural coupling (Lamb et al., 2021). The data was collected using an A-B-A approach of the fNIRS measurements. The A condition refers to the Baseline which takes place before and after the task (Baseline I and Baseline II). The Baseline serves as a control condition where no stimulus is presented to the participants. The B condition is when the stimulus is introduced to the participants; the stimulus will be 1 of the 5 tasks assigned to the teacher and student. The stimulus is measured as a block connected to time-locked hemodynamic responses acquired using fNIRS. The B condition is identified as the cumulative average of all the hemodynamic responses that occurred during the task. The A-B-A approach is repeated for all 5 tasks.

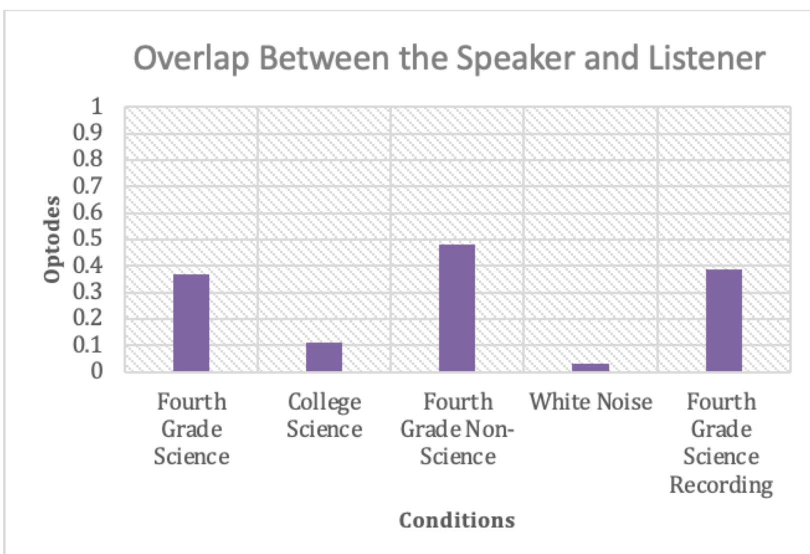
The data was processed using the fNIRS Soft Professional 4.10 software and Cognitive Optical Brain Imaging Software (COBI) Studio software 1.3.0.19. Preprocessing of data consisted of removing heart pulsations, respiration, and gross movement artifacts (Pinti et al., 2019, as cited in Lamb et al., 2021). There was approximately 11% data loss from the preprocessing of the data. Preprocessing was necessary before analyzing the hemodynamic responses due to the large quantity of data; there were over 50,000 points of data collected per session between a dyad.

3. Results

Results demonstrated significant and predictable brain neural coupling patterns occurring between the speaker and listener when the speaker's talk was successfully understood by the listener. This supports prior research that has analyzed the occurrence of brain neural coupling in classroom settings such as Lamb et al. (2021) used to model this study. Results from this study demonstrated similar outcomes to Lamb et al. (2021) for all 5 tasks.

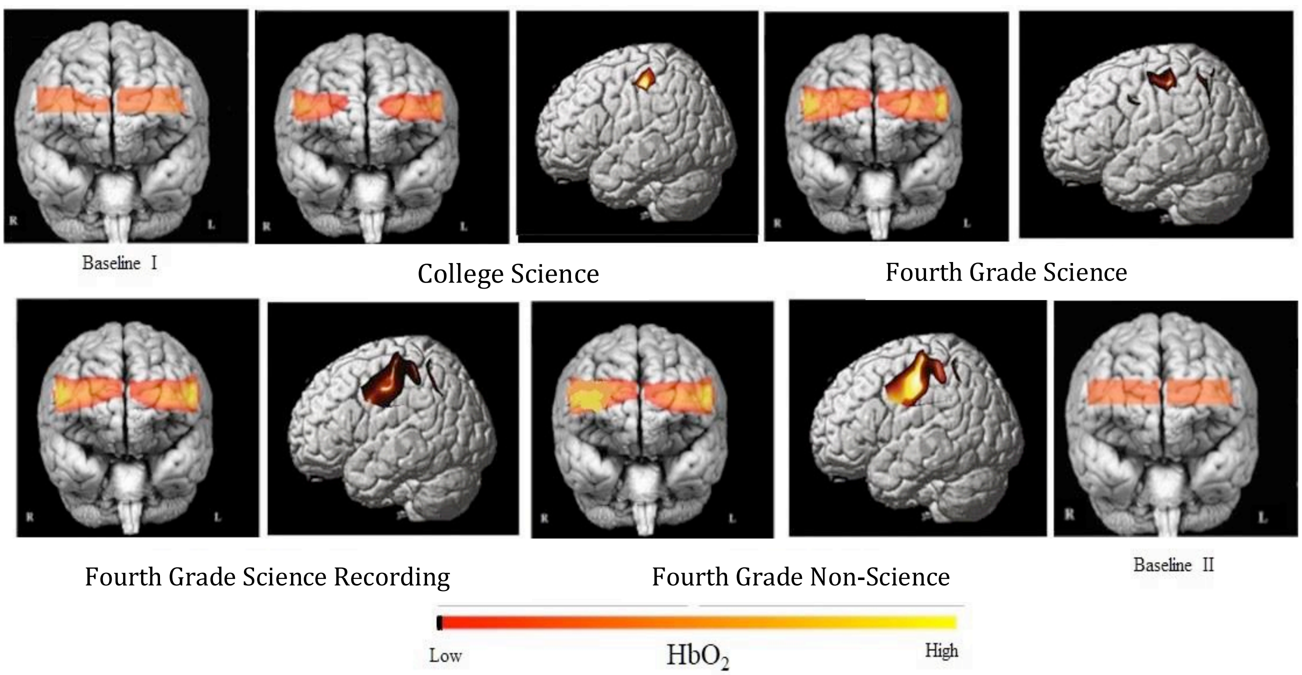
Results indicated brain neural coupling took place in a predictable pattern since the listener's (i.e., student) neural activity mirrors the speaker's (i.e., teacher) with a consistent delay of 6 seconds. All 16 teacher-student dyads that participated in this study demonstrated a 6 second delay during occurrences of brain neural coupling. The delay was seen in the participants' hemodynamic responses during the B condition of Task 1 (fourth grade science text), Task 3 (college science text), and Task 5 (recorded fourth grade science text). Results for the content tests aligned with brain neural coupling results since students' answers demonstrated understanding for Task 1 (M = 3.6 / 5.0), Task 3 (M = 4.1 / 5.0), and Task 5 (M = 4.0 / 5.0) with approximately 70-85% accuracy. Results reveal the highest intensity of neural coupling occurs during the reading of the fourth-grade non-science text (Task 3).

Condition	Significant Optodes: Overlap Between the Speaker and Listener	Mean (*M*) of Content Tests Scores
Task 1: Fourth Grade Science	.37 / 1.0 optodes	*M* = 3.6 / 5.0 questions
Task 2: College Science	.11 / 1.0 optodes	*M* = 1.2 /5.0 questions
Task 3: Fourth Grade Non-Science	.48 / 1.0 optodes	*M* = 4.1 / 5.0 questions
Task 4: White Noise	.03 / 1.0 optodes	Not applicable
Task 5: Recorded Fourth Grade Science	.39 / 1.0 optodes	*M* = 4.0 / 5.0 questions



In addition, results indicated brain neural coupling was not present when the speaker's talk was not understood by the listener. There was no significant brain neural coupling taking place in conditions where understanding did not occur. These conditions consisted of Task 2 (college science text) and Task 4 (white noise). Comparably, the content test demonstrated poor understanding for Task 2 (college science text) as students' answers averaged 1.2 / 5.0 or approximately 24% accuracy. The hemodynamic responses during Task 4 (white noise) were similar to the neural rest conditions (Baseline I and Baseline II) as minimal neural activity occurred during the B condition of Task 4.

The locations of neural activity remained consistent among all tasks where brain neural coupling occurred. The locations were identified through signaling in significant optodes, the most signaling was in the prefrontal lobe and parietal lobe**.** The optodes are deemed significant due to the levels of activation and its alignment with expected areas of activation associated with the occurrence of brain neural coupling. These areas of activation have been repeatedly identified during the occurrence of brain neural coupling in studies such as in Lamb et al. (2021) and Dikker et al. (2017). These studies identify activation of the prefrontal, parietal, and occipital regions of the brain. The prefrontal lobe is associated with executive functions such as attention and impulse control, the parietal lobe with processing of sensory information, and the occipital with visual perception and memory formation. As hypothesized, the greatest neural activity occurred in the parietal lobe and prefrontal lobe regions of the brain.



Results also demonstrate how level of understanding impacts the occurrence and intensity of brain neural coupling. In other words, the student's level of understanding of each text mirrors the intensity of brain neural coupling between a speaker and listener. This is seen through comparison of neural activity and content test results between Task 1, 3, and 5 to Task 2 (college science text). As previously mentioned, students averaged poorly on content understanding of the college text which correlates to the low intensity of brain neural coupling found in the hemodynamic responses collected during the B condition of Task 2. Contrastingly, students averaged a proficient understanding of the fourth-grade science text (Task 1), nonscience text

(Task 3), and fourth-grade science recording (Task 5) on content tests. Thus, the quantity of hemodynamic responses recorded during the B conditions of these 3 tasks was high and the intensity of speaker-listener neural coupling was high during the reading of each text.

4. Discussion

4.a. Individual differences

The conditions in which students understood resulted in the occurrence of brain neural coupling. Moreover, as the intensity of brain neural coupling increased, so did the level of understanding among students. This is illustrated when comparing the results of the fourth-grade science text and the fourth-grade non-science text. Based on results from content tests and questionnaires, students on average demonstrated a better understanding of content in the non-science text than in the science text. This is also shown in the intensity of neural coupling for Task 1 (fourth grade science text) and Task 3 (fourth grade non-science text). Task 3 displayed stronger brain neural coupling shown by the intense activity in significant optodes occurring in the B condition. This outcome may be due to the difference in language complexity between the science and non-science texts. As young readers, elementary-aged children are in the process of learning new words and building their vocabulary. Therefore, reading instruction in elementary classrooms largely focuses on building students' understanding of Tier 1 and Tier 2 words, and at times, Tier 3 words. The tiers are, Tier 1: basic, general vocabulary used in everyday interactions, Tier 2: academic words found across multiple disciplines, and Tier 3: specialized words that relate to specific domains. (Beck et al., 2002, as cited by Tompkins, 2014). The non-science text consists of more general everyday vocabulary (i.e., Tier 1 vocabulary) and academic vocabulary (i.e., tier 2 vocabulary). On the other hand, the science text includes general vocabulary, multiple-discipline vocabulary (i.e., Tier 2 vocabulary) and domain-specific vocabulary (i.e., Tier 3 vocabulary), such as luster, streak, and hardness to characterize rocks. Correspondingly, the increase of domain-specific vocabulary increases the complexity of the science text.

The difference in results between conditions where students did or did not understand can be attributed to the varying procedural and semantic networks of each individual student. To recall information from long-term memory, the information must be pre-existing in procedural and semantic networks of a learner's brain. Given the comparison between results for Task 1 and 3, it can be argued that students will reach a greater understanding of talk which contains related content to existing knowledge in their procedural and semantic networks. In turn, the talk between the speaker and listener will result in stronger occurrence of brain neural coupling. Thus, it can be stated that individual differences in existing procedural and semantic networks affect the occurrence and intensity of brain neural coupling in all conditions. In this study, the 16 student participants had sufficient background knowledge for brain neural coupling to occur between the speaker and listener in some conditions (Task 1, Task 3, and Task 5). This demonstrates that results may change depending on the group of student participants, the tasks students engage with, and the individual differences in semantic and procedural networks among students.

This finding can further be applied to the college science text where minimal brain neural coupling occurred between the speaker and listener. The complexity of the college science text is due to the higher-level academic language and prominent use of domain-specific vocabulary. The outcomes of Task 2 in comparison to Tasks 1 and 3 highlight the significance of the language complexity and intended audience of each text. The college text is based on an entry-level geology textbook for college freshmen. The intended audience is college students who have acquired knowledge of general science topics and are being introduced to a specified science topic in more detail. The fourth-grade non-science and science texts are excerpts from fourth grade textbooks that include content from the fourth-grade curriculum of the participants' residential U.S. district. On the other hand, the intended audience for the science text are fourth grade students who are at the beginning stages of building knowledge of broad science topics. Therefore, the fourth-grade texts included content which is presumably in similar levels of the students' existing knowledge and understandings. This allowed for students to build strong connections to the content. Meaning, the talk allowed students to activate prior knowledge and integrate the related information to the talk. Through the ability to make connections to prior knowledge, students built a stronger understanding of the fourth-grade science text compared to the college science text. Thus, it can be argued that the audience the text is written for (complexity) will impact the occurrence and intensity of brain neural coupling. In all, the intensity of brain neural coupling is dependent on the background knowledge of the individual and retrieval of information from their procedural and semantic networks. Further research could focus on identifying the exact difference (e.g., differences in background knowledge, personal academic interests) between individuals from specific student populations that contribute to the occurrence and intensity of brain neural coupling. The research could focus on solely testing a specified student population (e.g., multilingual learners, neurodiverse learners, etc.) and comparing results between individual students and/or results from this study.

4.b. Implications of brain neural coupling

This study aimed to answer how brain neural coupling can be utilized to improve or introduce new teaching strategies or pedagogies. Results demonstrate the possibility of utilizing brain neural coupling as an assessment tool to gauge student understanding and learning outcomes. The process of brain neural coupling is fundamental to learning since it is a basic neurological process that occurs when understanding is reached (Lamb et al, 2021). Brain neural coupling is an indicator of understanding occurring between a listener and speaker. In this study, understanding was measured using brain neural coupling and content tests and questionnaires. Similarly, in elementary classrooms, assessments are commonly used to measure a student's knowledge of concepts through various formats (e.g., diagnostic, formative, summative, standardized) Assessments help teachers and instructional designers make decisions on instruction and curriculum based on students' learning outcome, abilities, and background knowledge. Assessments allow teachers to understand individual students' background knowledge and personal experiences, alter instruction to support student learning, target specific student needs, etc. (Tompkins, 2014). Results demonstrated how brain neural coupling may work to provide similar results as content tests due to the similarities between results in content tests and brain neural coupling in Task 1, 2, and 3. Thus, like content tests and other forms of assessments, brain neural coupling can potentially be used as an assessment tool to aid teachers in making well-informed instructional decisions. One specific way this could be performed is using brain neural coupling to identify the zone of proximal development of individual students. Vygotsky's zone of proximal development refers to the area of development where a learner can do an activity with the support of a more knowledgeable individual (i.e., teacher) (Gauvain, 2008). Identifying the zone of proximal development ensures instruction and teaching strategies are guiding students towards gradually developing new skills and knowledge. It involves meeting students where they are and providing effective instruction that works to build on top of their abilities to reach mastery of content. Thus, identifying the zone of proximal development for individual students and/or specific student populations (e.g., multi-language learners) will aid teachers in differentiating instruction and providing accommodations for diverse student needs. The potential for brain neural coupling as an assessment tool is demonstrated through the differences in results among the 5 conditions. Significantly, results from this study indicate that the science college text (Task 2) is beyond the students' zone of proximal development. This is because even with teacher assistance, the excerpt was read aloud by the participating teachers, the students had difficulty comprehending the talk.

Furthermore, there are limitations to typical assessment strategies used in the modern classroom. Assessments may fail to give a full picture of student understanding of content, such as, if questions on a test do not prompt students to use information they may be knowledgeable about (e.g., closed-ended vs. open-ended questions). Therefore, when tested, students do not engage in the recruitment of resources from long-term memory and the test does not accurately measure what a student understands. In addition, some assessments are limited by time. For content tests, it takes time for students to complete the test and for teachers to grade and/or assess student learning. By the time the results have been analyzed, a students' understanding and acquired knowledge may have undergone changes not demonstrated in the test. Thus, test results do not accurately reflect changes in students' understanding and abilities over time. This may portray inaccurate student understandings as well as lead teachers and instructional designers to make ineffective instructional decisions. Alternatively, brain neural coupling provides a way to view students' understanding more immediately, as the conversation is taking place, and changes over time. Moreover, brain neural coupling provides an indication of student comprehension as well as the level of comprehension, demonstrated by the occurrence and intensity of neural coupling. Further research must be conducted to determine how brain neural coupling as an assessment tool may be utilized in realistic classroom settings. For instance, Lamb et al. (2021) suggests observable student behaviors associated with the occurrence of neural coupling can be used to identify if brain neural coupling is taking place during a classroom activity.

Results support findings in past studies, such as Dikker et al. (2017) and Lamb et al. (2021, which demonstrate how brain neural coupling has potential to be used as a reference system to predict student's learning outcomes, engagement, and teaching preferences. Results from this study could also possibly identify individual student interests or student preferences for certain teaching strategies. One way this could be conducted is by comparing the results of brain neural coupling and neurocognitive differences among conditions incorporating different forms of media and/or delivery of talk. In this study, we can compare the intensity of neural coupling that took place in Task 1 (fourth grade science text) and Task 5 (fourth grade science text recording). The tasks consisted of similar fourth grade science content but were delivered in two distinct ways, talk between two individuals versus a recording of talk. In comparison, neural coupling was among the same level of intensity for the recording of the science text (Task 5) and the fourth-grade science text (Task 1). Task 5 showed slightly more neural activity in significant optodes during the B condition. This may suggest that the student participants preferred the recording of the talk rather than one-on-one talk with the teacher. Although, it is difficult to isolate the reason for the slight difference as it could be the result of the form of media, delivery of talk, or content and academic language differences among the two textbooks used for these conditions.

To begin effectively translating findings from cognitive neuroscience to the elementary classroom, further research must be conducted to discover how brain neural coupling can be utilized to inform instructional decisions. Specifically, research may target distinct student populations of interest (e.g., multi-language learners, neurodiverse learners) to inform how to effectively differentiate and accommodate for the varied individual needs of these student populations.

5. Conclusion

The purpose of this study was to discover how findings in cognitive neuroscience can benefit teaching strategies and pedagogies in elementary classrooms. The study focused on the neurocognitive processes occurring during talk between a speaker (i.e., teacher) and listener (i.e., student). Results of this study displayed that individual differences in cognition impact the occurrence and intensity of brain neural coupling between the speaker and listener. The individual cognitive differences are due to the available semantic and procedural networks varying between student to student.

This study promotes the use of talk in instruction in elementary classroom settings. Brain neural coupling has been shown to occur when talk is understood between a speaker and listener. Additionally, brain neural coupling explains what takes place as students engage in talk when considering Process 2. Brain neural coupling demonstrates the underlying mechanisms associated with learning new information, the process of internalization. As talking takes place, a student makes connections to prior knowledge and recruits cognitive resources to comprehend the information associated with the talk. In turn, the student connects the newly presented knowledge to existing understandings and strengthens their comprehension. Therefore, findings in this study promote increased integration of talk in classroom instruction to strengthen cognitive processes associated with learning. Brain neural coupling during talk supports the effectiveness of talk-based pedagogies and teaching strategies such as Vygotsky's sociocultural theory, Dialogic Teaching, grand conversations, etc. (Gauvain, 2008; Reznitskaya, 2012; Tompkins, 2014). The study also contributes to findings that support the use of brain neural coupling as a reference system to predict student learning outcomes (Dikker et al., 2017; Lamb et al., 2021). Specifically, it suggests the potential use of brain neural coupling as an assessment tool to gauge an individual student's zone of proximal development. Further research must be conducted to gain a better understanding of how brain neural coupling can serve as a tool to inform instructional decisions in realistic classroom settings. Research can more closely examine brain neural coupling in specific student populations (e.g., multilingual learners, neurodiverse learners) and provide further understandings of differentiation and accommodation for the diverse needs of the specific student population.

6. References

Atwood, S., Turnbull, W., & Carpendale, J. I. M. (2010). The construction of knowledge in classroom talk. *The Journal of the Learning Sciences*, *19*(3), 358–402. http://www.jstor.org/stable/20799332

Dikker, S., Wan, L., Davidesco, I., Kaggan, L., Oostrik, M., McClintock, J., Rowland, J., Michalareas, G., Van Bavel, J., Ding, M., & Poeppel, D. (2017). Brain-to-brain synchrony tracks real-world dynamic group interactions in the classroom. *Current Biology*, *27*(9), 1375–1380. https://doi.org/10.1016/j.cub.2017.04.002

Gauvain, M. (2008). Vygotsky's sociocultural theory. Encyclopedia of infant and early childhood development (pp. 404-413) https://doi.org/10.1016/B978-012370877-9.00170-5

Lamb, R., Fortus, D., Sadler, T., Neumann, K., Kavner, A., & Annetta, L. (2022). Exploration of teacher-student neural coupling occurring during the teaching and learning of science. *Educational Innovations and Emerging Technologies*, 1(1), 15–31. https://doi.org/10.35745/eiet2021v01.0 1.0003

May, P. L. (2020). Number talks benefit fifth graders' numeracy. *International Journal of Instruction*, 13(4), 361–374. https://doi.org/10.29333/iji.2020.13423a

Reznitskaya, A. (2012). Dialogic teaching: rethinking language use during literature discussions. The Reading Teacher, 65(7), 446-456. https://doi.org/10.1002/TRTR.01066

Tompkins, G., E. (2014). *Language arts: patterns of practice*. Pearson Education Limited.