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Second-Grade Students' Achievement and Engagement in Inquiry-Based Learning: An Exploratory Study

Jeremy Winters*, Katie M. Schrodt, Tracey Huddleston
Middle Tennessee State University, Murfreesboro, 37132, United States

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A B S T R A C T

This exploratory study examined 3 second-grade classrooms in the southeast United States. The purpose was to determine the effects and feasibility of implementing various levels of inquiry-based instruction. The study used structured, guided, and open inquiry in the project. The central content focus was on mimicry using a unit of study around pill bugs. This article reports on the unit that was implemented, results of the implementation, and implications for teachers desiring to implement inquiry-based instruction into the classroom.

1. Introduction

Can 2nd grade students independently develop a meaningful question to investigate? How much scaffolding do 2nd graders need to participate effectively in inquiry-based instruction? Similar to the first three phases of White (1998) list of five inquiry-based phases – question, predict, experiment, model, apply – we began our exploratory project-based inquiry study with these questions. Project-based instruction is a teaching model that has been shown to have positive effects on student achievement (Krajcik, J. S., & Shin, N., 2018). Inquiry based instruction is a popular teaching approach with a non-linear path of research support (Oliver et al., 2021). Previous research on the effectiveness of inquiry instruction versus traditional science instruction showed inquiry instruction resulted in gains in student achievement (Abdi, A., 2014; Alghamdi, A., 2017). Lee, H. S. (2020) indicated that inquiry affects student achievement specifically within the area of conceptual understanding. Moreover, many educators accept inquiry-based teaching as "best practice" without question. However, some research calls into question the effectiveness of inquiry-based research, especially when students are responsible for naming the question for investigation themselves (Oliver et al., 2021). While some research has shown that inquiry-based instruction does positively impact students' inquiry skills (Firman et al., 2019). Some studies have attempted to provide guidance on how to help teachers navigate the process of getting student generated questions (Van Uum et al.,2016;

* Corresponding author.
E-mail: katie.schrodt@mtsu.edu
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Dobber et al., M., 2017). But our work indicated that teachers still needed more guidance in this area. Research suggests students who reported experiencing high levels of inquiry-based teaching experienced higher than average engagement and motivation, but lower than average scientific literacy (Oliver et al., 2021). Another result from inquiry based instruction indicated by research is increased creativity by students (Lu et al., 2022). This literature review along with our work with teachers led us to predict that 2nd grade students would likely be engaged in the work, but not have the ability to develop a meaningful question to study without significant scaffolding.

For the experimentation phase, we investigated the term *inquiry-based instruction*. Research and pedagogy have many different definitions and procedures for this one term (Pedaste et al., 2015; Solé-Llussà et al., 2022). Our research question focused on 2nd graders' ability to participate in project-based inquiry instruction, and considered how much information should be provided to students and how much guidance should be provided as the teacher. Based on this, we used a continuum of four levels of inquiry to frame our study: Confirmation, Structured, Guided, and Open (Banchi., 2008; Sampson., 2020).

Table 1. Levels of Inquiry and What is Given to The Learner

Level of Inquiry	Problem / Question	Procedure	Solution
Confirmation	X	X	X
Structured	X	X	
Guided	X		
Open	X		

Table is adapted from Banchi (2008)

In *confirmation inquiry*, students are given a question and a solution. The results are already known, and the students are taken through the scientific process to confirm the results. In *structured inquiry*, the teacher still provides a question and a step by step plan to discover the results. The students essentially follow a "recipe" given by the teacher to determine a solution. In *guided inquiry*, the teacher gives the students the question only. The students are asked to determine the best method for solving the question. Lastly, in *open inquiry*, the students Lastly, in *open inquiry*, the students are at the center of the work and are expected to derive their own questions and develop and carry their own methods and procedures, as well as report the investigation results.

2. Methodology

For this study, we created three conditions in three different classrooms. Each classroom was assigned as one level of inquiry - structured inquiry, guided inquiry, or open inquiry. Our investigation took place in three 2nd grade classrooms which had 16 students in each class. In order to control for teacher effect, the researchers led all instruction with the classroom teacher present. The unit consisted of 3 one-hour lessons adapted from Morgan (2013) *Picture Perfect STEM's Pillbots* unit. The first 1.5 days were identical in all three classes. During the last 1.5 days, three levels of inquiry were established, one in each of the 2nd

grade classrooms. One classroom was the "structured inquiry" classroom, one was the "guided inquiry" classroom, and the last was the "open inquiry" classroom.

The First 1.5 Days

The first 1.5 days were identical in each of the three classrooms. Day one began with a large photograph of a pillbug and reflection questions, have you seen one of these before, where did you find it, what did you do with them, what do you call them? As students began to talk, they began to activate their prior knowledge, making connections to seeing "rolly pollies" in the real world. Students' prior knowledge was then assessed by an anticipation guide, where students answered five true or false questions about their knowledge of pillbugs.

After the anticipation guide was complete, each student was allowed to choose a pillbug from the habitat. The pillbugs were placed into a small paper cup with an open air lid. Each cup contained a wet paper towel and some leaves and dirt. Using the pillbug observation page provided by Morgan (2013) Picture Perfect STEM's Pillbots unit, the students were guided to draw a sketch of their pillbug and observe their legs and body parts. The students also observed their pillbug's reaction to certain stimuli, including what happened when they touched the pillbug, turned it over, or moved it to a dry place. (See Figure 1)

After the students were given ample time to observe and write, the students participated in a roundtable discussion. In this discussion, the students asked and answered questions related to their experiences with the pillbugs. *What did you notice about your pillbug? How did your pillbug react in the different situations? What evidence do you have that any of the statements on the anticipation guide were true or false? Did you learn anything new about pillbugs through your observations?*

The discussion led into an interactive read aloud of the book *Next Time You See a Pillbug* by Morgan (2013). Students were asked to listen for evidence confirming or disconfirming their prior knowledge of pillbugs. A hallmark of interactive read alouds is for students to be given time to stop, process, and talk in designated stopping points during the reading. One spot in particular allowed students to engage in new and important discipline specific vocabulary. For this lesson, it was important for the students to understand the term "segmented exoskeleton." The students were asked to turn and talk about what they noticed about the outside shell of the pillbug. They were introduced to the term "segmented exoskeleton" and given a kid-friendly definition: a hard outer covering that is divided into sections.

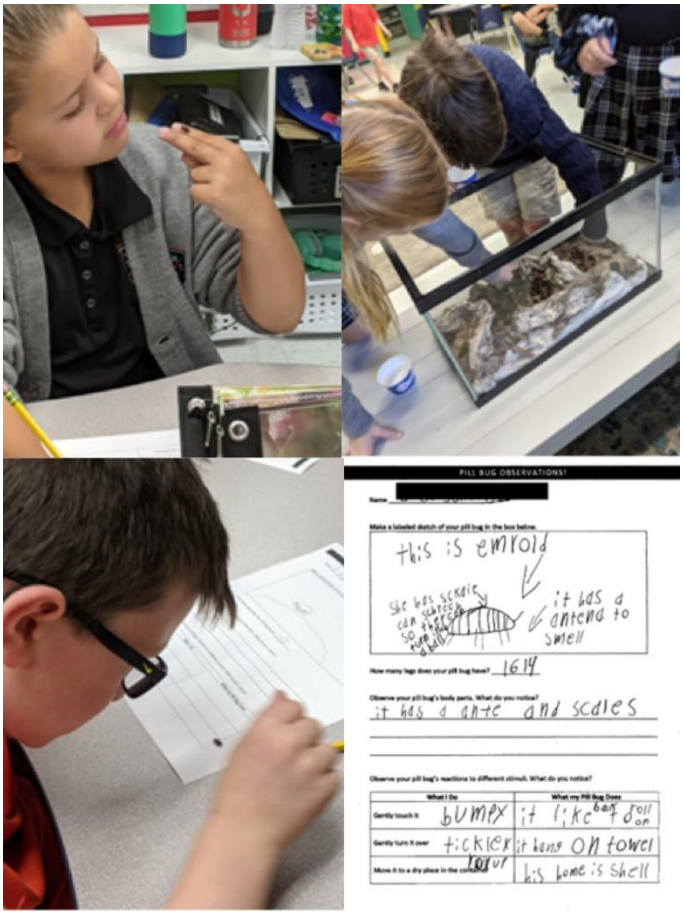


Figure 1. Students Investigating and Documenting Pillbug Behavior

In order to support the understanding and memory of this definition, the students were given hand motions to match the definition. The students moved their hands from left to right, in separated sections, saying “seg-ment-ed” broken down into its syllables. Then the students crossed their arms into an X against their bodies, while they said “exo” and then they put their arms into a strong pose as they said “skeleton.” Each part of the hand motions helps the students understand the meaning. In the beginning, the word segmented is literally broken down into “segments” or sections as the students move their hands in small segments as they say the word. The X next to their bodies helps the students remember the difficult word “exo” but also indicates the outside of the body as it touches them. Lastly, the skeleton muscle hand motion, helps students remember that the exoskeleton is strong. (See Figure 2)

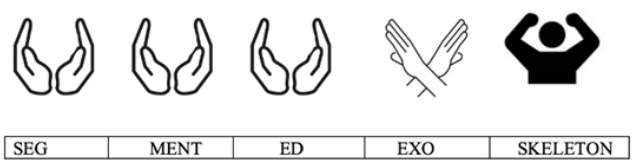


Figure 2. Hand Motions for the Vocabulary Word Segmented Exoskeleton

After the interactive read aloud, the students were asked to go back to their anticipation guide and fill out the "after reading" portion, indicating their new knowledge gained from the reading. The day closed with students reflecting on their learning and naming their pillbugs.

The next morning, the students were reminded of the unique feature of a pillbug- its segmented exoskeleton. The students explored how scientists have tried to copy this unique feature when creating robots by watching a video of a "Pillbot," a robotic pillbug used to gain access to small, dangerous places unfit for humans. The segmented exoskeleton of the robot allows it to roll up and use its hard shell to protect itself from elements such as fire. Students were then introduced to the term "biomimicry." The student-friendly definition is "imitating living things to solve human problems." The word was broken down into its most meaningful parts "bio" means life and "mimic" means to imitate. The students were again given hand motions to help solidify the learning of this vocabulary. For the word "bio" the students lifted their arms to take a deep breath, indicating life. For the word "mimicry" the students would "mimic" whatever the teacher did with her hands, similar to a mime. (see Figure 3)

Figure 3. Hand Motions for the Vocabulary Word Biomimicry

Students then read the book *Robots* by Stewart (2015). The students learned that roboticists study nature to help inspire the creation of their robots. The students discussed important essential questions such as, *What kinds of animals did roboticists study to design the robots you learned about?* and *Why do* roboticists study animals? Table 2 gives an overview of the first 1.5 days of instruction.

Table 2. Overview of the First 1.5 Days of Instruction

Day 1	● Anticipation guide ● Explore and Observe Pillbugs ● Interactive Read aloud of Next Time You See a Pillbug by Emily Morgan (2013) ● Vocabulary Instruction for "segmented exoskeleton"
Day 2 (first half)	● Pillbot video ● Vocabulary Instruction for "biomimicry" ● Read *Robots* by Stewart (2015)

The Final 1.5 Days

For the final day and a half, each room was assigned as a level of inquiry. The assignments were made based upon time. For example, the Open Inquiry class did

not have somewhere else to be after the set time we were given for the lesson. Although we never exceeded the time allotted, we predicted we may need more time in the Open Inquiry class than the Structure Inquiry class. Table 3 outlines the levels of inquiry for each class. Each class is described in detail below.

Table 3. Level of Inquiry by Classroom

Level of Inquiry / Classroom	Problem / Question	Procedure	Solution / Culminating Product
Structured Ms. Ada	Problem given to students: Babybel Cheese Company Test Team. The Test Team is responsible for determining if the Babybel packaging can withstand heat, water, chemical reactions, and impact.	Procedure given to students: Conduct heat, water, chemical reactions, and impact tests.	Overall Evaluation Page. Does the test team recommend Babybel cheese wrappers as packaging for drone deliveries? Yes or No.
Guided Ms. Cami	Problem given to students: How can Babybel reuse the cheese packaging to reduce waste?	Students determined a procedure to solve the given problem.	Students decided to demonstrate how the cheese packaging was going to be used in either a picture or model, incorporating one additional unique characteristic of the Pillbug.
Open Ms. Kate	Students determine a human problem that could be solved using characteristics of a Pillbug.	Students determine a procedure to solve their problem.	

Structured Inquiry

Ms. Ada's class was selected to explore Structured Inquiry. For this class, the specific question and procedures were explicitly given to the students. The students were responsible for carrying out the procedures correctly in order to determine a response. For this reason, additional time was required to complete the activities described above. For the culmination of the unit, the students were asked to be part of the "Babybel Cheese Company Test Team." Through discussion, it was noted that the red packaging around the Babybel cheese protects the cheese just as the outer shell protects the pillbug. Capitalizing on this similarity, the Test Team would like to create ways to repurpose the cheese packaging to minimize waste. In order to do this, Babybel has partnered with a shipping company to reuse the cheese packaging in shipping items via drones. The Test Team is responsible for determining if the Babybel packaging can

withstand heat, water, chemical reactions, and impact. Four tests were explained with exact procedures to follow.

Test 1 (Heat)

To determine if the packaging could withstand heat, a piece of paper was placed inside the Babybel packaging. A parent then used a blowtorch on the packaging for 10 seconds. All students watched from a safe distance. After cooling, the packaging was opened to see if the paper was at all affected.

Test 2 (Water)

To test the ability of the packaging to keep out water, the Babybel was submerged in water for 20 seconds. The packaging was dried, and then opened. The cheese was tested to see if it was wet or not. Figure 4 shows students conducting the Babybel cheese water test.

Figure 4. Students Conduct the Babybel Cheese Water Test

Test 3 (Chemical reactions/elements)

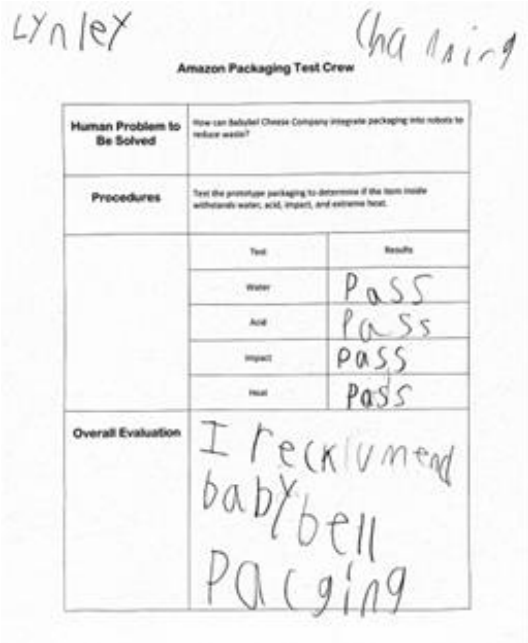
The Clean Penny activity was used to test the Babybel packaging as protection against chemical reactions and other elements. First, the students were asked to predict if a penny submerged in ketchup or mustard would clean a penny, or neither or both. After an initial test was run, the students determined the ketchup cleaned the penny. The Babybel packaging was then used to see if it could keep a penny dirty. A penny was put into a package and then submerged in ketchup. The penny was then removed to see if the packaging protected the penny.

Test 4 (Impact)

To see if the Babybel packaging could withstand dropping from a drone, a mint was placed inside the packaging. Students then threw the packaging against a

brick wall. The packaging was then opened to determine if the mint was cracked or broken.

After all tests were run, the 2nd grade students worked with a partner to write a report to Babybel as to whether to utilize the waste packaging for shipping or not. Each partner group was provided an *Amazon Packaging Test Crew* data sheet. The students recorded the data for each of the four tests, answering 'yes' or 'no' after completing each of the experiments. The students were asked to determine an Overall Evaluation of whether or not they would recommend Babybel cheese packaging to Amazon. Figure 5 shows the testing sheet with results from one group. This group was the only group to provide a final recommendation stating, "I recommend Babybel packaging." The rest of the groups determined that the Babybel packaging might not be the best way for Amazon to reduce waste and ship items.


Amazon Packaging Test Crew

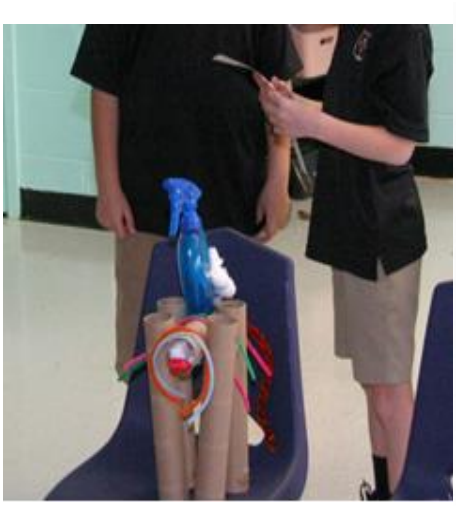
Human Problem to Be Solved	How can Babybel Cheese Company integrate packaging into robots to reduce waste?	
Procedures	Test the prototype packaging to determine if the item inside withstands water, acid, impact, and extreme heat.	
	Test	Results
	Water	Pass
	Acid	Pass
	Impact	Pass
	Heat	Pass
Overall Evaluation	I reckumend babybell Packging	

Figure 5. Amazon Packaging Test Crew Sample Recording Sheet

Guided Inquiry

To explore Guided Inquiry, Ms. Cami's class was given a specific problem, but not a procedure to use to solve it. The class was given the following problem, "How can Babybel reuse the cheese packaging (simulating the segmented exoskeleton) to reduce waste?" As part of the problem, students were asked to demonstrate how the cheese packaging was going to be used in either a picture or model while incorporating one additional unique characteristic of the Pillbug. Since students were asked to create something, the last half of day 2 was spent with students brainstorming ideas and materials needed. Students were asked to give us a list of items they would need to create the visual. Day 3 involved the students creating and presenting the ideas to the rest of the class. For the final 1.5 days, students worked with a partner.

The Guided Inquiry class demonstrated creativity and thinking skills through the robots they created to reduce the waste from the wrapping around a Babybel cheese. For example, one group created a robot named "Blue Army." This robot "lives in the ocean and eats all the trash he can find." (See Figure 6). A few students designed a robot to clean up the trash similar to a self propelled vacuum cleaner. One group explained that the wrapper can "turn into a ball with a camera and shoot water." This was interesting in that this was the only group stating the wrapper could become something different and be useful rather than waste to be discarded.



Human Problem to Be Solved	How can Babybel Cheese Company integrate packaging into robots to reduce waste?
Name of Robot	BLUE ARMY
Description	We Sallyd all the trash in the ocen ape Robot will eat the trash in the ocean and cob ov

Figure 6. Guided Inquire Blue Army Example

Open Inquiry

Ms. Kate's class was not given a specific question or procedure. Therefore, the last half of Day 2 involved the students thinking about a human problem that could be solved using characteristics of a pillbug. For this reason, the last half of Day 2 was spent brainstorming a problem. Students worked in groups to create a picture or model. By the end of Day 2, each group was required to have a list of items needed to create the visual. The last day (Day 3) involved the students creating and presenting the visuals. During the presentation, students stated the human problem being solved as well as connecting characteristics of the pillbug.

The Open Inquiry class identified a problem then created a robot with similar characteristics of a Pillbug to solve the problem. For example, one group created a "battle boat" named "Water Runner M.13." The hard shell (like the Pillbug) of this boat is designed to help the Navy save other boats from sinking. Similarly, the "Fing Pillbug" from another group, was created with 14 hooks to "help people who play sports not forget their hats." And the "Thunder Head" has antennae and a hard shell (like the Pillbug) "to help detectives." (See Figure 7)

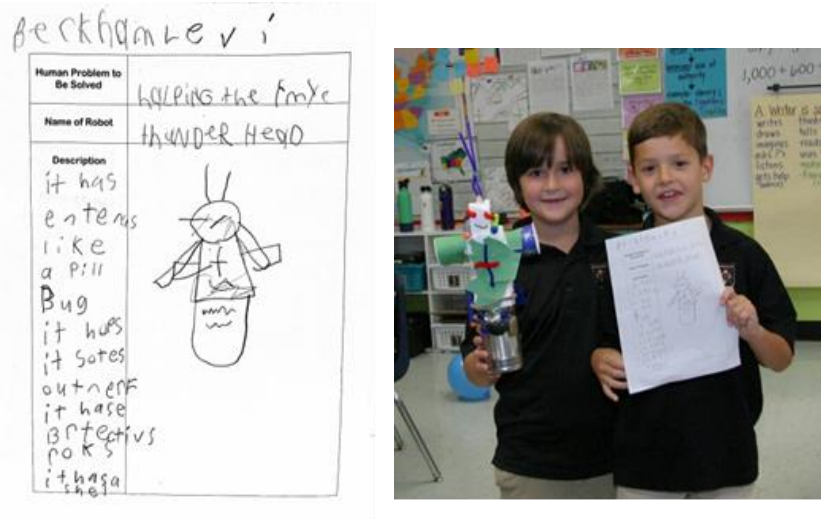


Figure 7. Open Inquiry Example

Each of the three types of Inquiry explored resulted in high levels of engagement. We believe this result was achieved due to the task designed for each. During a final debrief in each classroom, we described all three projects/tasks to every student. All students reported enjoying the project/task they were given in their classroom the best as compared to the projects/tasks from the other second grade classrooms. The Guided Inquiry and Open Inquiry allowed for ingenuity through creating solutions, and the Structured Inquiry provided experimentational thinking through the prediction and carrying out of specific procedures. Finally, our hypothesis that second grade students would struggle to develop their own problem and procedures to develop an answer was mixed. The students needed a lot of scaffolding that would have been difficult to achieve without the human resources we had in our exploration. The majority of problems that were developed by the students were some form of the ones presented in the read-aloud. This indicates that the students were dependent on the read aloud content in order to come up with their own problems and ideas. Without this support, it is unclear whether the students would be able to identify a problem alone.

3. Results and Discussion

Overall, the results from our second-grade project-based inquiry instruction experiment aligned with the literature on increased student achievement, engagement, and creativity. Our study revealed that in terms of teachers, a significant amount of time is required for each level of inquiry. When thinking of the levels of inquiry as a continuum, time also fell in alignment with the continuum. The teacher had to spend significant time on the front end planning or significant time during the investigation, the balance depending on the level of inquiry. Structured inquiry is preparation heavy, requiring time up front for the teacher to plan the investigation and organize all of the materials. Guided inquiry required less time on the front end, but required more time as the students planned their investigation. Open inquiry required the least amount of preparation and planning prior to the lesson implementation, but required the most amount of time on task with student projects in the classroom.

Similarly, each level of inquiry required a level of support from extra staff or volunteering adults. The structured inquiry required help with the set up, as teachers were needed to organize and pass out the many materials planned by the teacher for the investigation. The open inquiry required the most extra help during the investigation as adults had to provide significant scaffolds for students as they thought through their questions and determined their method. Similar results were found regarding instructional roles and the need for explicit instructions with kindergarten students as cited in the literature (Jiao et al., 2022; Schmerse et al., 2024). The time in the open inquiry carried a heavy cognitive load as teachers tried to help students become unstuck without handing them ideas. Time was also required for procuring supplies as students thought of new ideas for their investigations. This included multiple trips to the Maker's Space as well as the grocery store to get what was needed. Teachers need to be aware of the amount of human resources needed in order to enact each type of inquiry for planning purposes, similar to the finding of Morales et al., (2022). As the project progressed, it became evident the students were not able to develop a meaningful question on their own and consequently needed quite a bit of scaffolding to participate effectively in the project.

Students were motivated and engaged similarly across all three conditions. Each day students were excited and engaged in the work. Students in each condition reported they loved the group they were in and would not want to change groups. This aligns with previous research that states inquiry based teaching produces high levels of motivation in learners as well as positive self-efficacy (Hong et al., 2017; Hana et al., 2020; Oliver et al., 2021; Zheng et al., 2022).

Students definitely struggled to come up with their own questions in the open inquiry. Wu et al. (2023) found that utilizing a technology aid can assist students in generating questions. In our study, generating questions required lots of scaffolding, including extra adults in the room to help students think. Students gleaned many of their ideas from the book that was read or directly from teacher help rather than their own creativity. This was some of the students' first time to participate in true open inquiry. The classroom teacher later reported that she tried again and the students seemed to do better. It could be that students need practice with this type of inquiry, and doing it consistently across the year could show improvement. It is also possible that doing guided inquiry well in younger grades will set the stage for later grades to do more effective open inquiry. Setyawan et al. (2020) found that utilizing videos followed by guided inquiry can positively impact student achievement. In our study, the Pillbot video limited student creativity, but did not hinder student achievement.

There is a place in the classroom for all three types of inquiry. Each level of inquiry has its own benefits and purposes. It is important that students experience each type throughout the year, as they hone in on a continuum of skills. When students participate in each type of inquiry, they work on everything from precision of carrying out a procedure and finding the solution to curiosity and ability to form a critical question and investigation.

Clearly, each of the types of Inquiry encouraged creativity and application of learning. The Guided Inquiry and Open Inquiry allowed for creativity through creating solutions and the Structured Inquiry also provided higher order thinking through specific tasks and creating solutions as well. The students were engaged in the tasks, worked well together, and demonstrated learning. Other studies have found similar results in regard to creativity and engagement (Aydın., 2020; Aran., 2024).

4. Conclusion

The ability of second grade students to develop their own question for investigation and whether each level would produce similar effects to the others was the motivation of this exploratory study. As we engaged with the three classes in the three different levels of inquiry, task selection, time, and human resources were key themes that emerged. If teachers can situate the unit around interesting and engaging tasks, student learning and motivation will be high despite the level of inquiry being implemented. The time and human resource elements of our study indicated that teachers will need to consider time in planning/enactment based upon the level being implemented and the need to recruit more aid in the classroom as the level of inquiry increases. Having more help to guide students in thinking about problems was very important in our study. To conclude, early elementary students need opportunities with all levels of inquiry even though they may struggle to begin. This article has provided teachers with a sample unit and considerations for implementing the unit.

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