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The effects of functional writing contingencies on second graders' writing and responding accurately to mathematical algorithms

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ABSTRACT

We tested the effects of a functional writing protocol on the accurate functional and structural responses in mathematical algorithms written and read by 6 typically developing 2nd grade students using a delayed pre- and post-experimental probe design. The participants wrote an algorithm on how to solve word problems and observed their peer completing the steps written in the algorithm. A yoked-contingency game board was implemented in which both the participants and the peers could move up on the game board if the peer was able to solve the word problem based on the participant's written algorithm. The results showed an increase in the number of functionally accurate written algorithms written by the writers as a function of the procedure.

KEYWORDS: writing, algorithm, mathematics, word problems

A recent study reports that fourth grade students in the USA perform 11th in mathematics compared to other economically advanced countries, while eighth graders in the USA perform 9th (Gonzales, Williams, Jocelyn, Roey, Kastberg, & Brenwald, 2009). Even though mathematics performance scores of American students have increased from 1995, there is still a need to further improve American students' mathematics scores. One of the important components of mathematics includes the writing of, and accurately responding to, written mathematical algorithms. The National Council of Teachers of Mathematics (NCTM, 2000) outlines the goals of mathematics education. Students need to be able to not only solve word problems they also need to be able to communicate effective mathematical operations through writing. NCTM states that students should be able to:

> *....organize and consolidate their mathematical thinking through communication; communicate their mathematical thinking coherently and clearly to peers, teachers, and others; analyze and evaluate the mathematical thinking and strategies of others; use the language of mathematics to express mathematical ideas precisely (p. 60)*

Joining language and mathematics instruction is seen as a key curricular activity (Candia, 1998). One of the benefits of linking writing and mathematics is to allow teachers to identify their students' deficits in producing and responding to math algorithms (Rothstein & Rothstein, 2007). Researchers have also reported improvements in students' mathematical skills when students were asked to write about their mathematical thinking (Cai, Jakabcsin, & Lane, 1996; Fukawa-Connelly & Buck, 2010; Kline & Ishii, 2008; Langer & Applebee, 1987; Staats & Batteen, 2009). Skinner's (1957) theory of verbal behavior may offer an effective operational approach to this educational objective.

"Writing-to-learn" is an approach in teaching mathematics that incorporates writing and language instruction. It is theorized to be a way to enhance learning where learners develop the skills to communicate mathematical operations as well as to follow algorithms (Johanning, 2000; Kline & Ishii, 2008). Writing-to-learn in mathematics also supports student learning because as with writing in other curricular areas, students are required to "organize, clarify, and reflect on their mathematical thinking" (Burns, 2004; Gammill, 2006).

Some examples of writing-to-learn activities include the use of journal writing, reports, essays, solving math problems, explaining mathematical ideas, expository writing, and writing about learning processes (Burns, 2004; Johanning, 2000). Researchers have reported that the use of "writing-to-learn" in their mathematics classroom resulted in better student performance, and better student understanding of mathematical concepts and their own learning processes (Burns, 2004; Cai, Jakabcsin, & Lane, 1996;

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Flesher, 2003; Fukawa-Connelly & Buck, 2010; Staats & Batteen, 2009; Zollman, 2009). Unfortunately, the actual stimulus control and responses involved in the process and the procedures used in the studies lack clarity.

Although research on "writing-to-learn" in mathematics has demonstrated the effects of writing on overall academic achievement, the procedures implemented could not be directly observed and measured. One of the several branches of language research involves the function of language from a behavioral perspective and is called verbal behavior analysis. Skinner (1957) set forth the initial theory that led to basic and applied research in verbal behavior and its development. The contributions of this analysis to education, speech therapy, and language development has grown exponentially in the last two decades, leading to the identification of environmental experiences that contribute to productive and emergent language functions (Barnes, Holme, Barnes-Holmes, & Cullinan, 1999; Greer, 2008; Hayes & Hayes, 1989; Michael, Palmer, & Sundberg, 2011). Findings of these analyses have complemented current findings in language development by providing evidence of the role of experience in the emergence of language (Hoff & Shatz, 2009). In the field of Verbal Behavior, writing is a type of verbal behavior that extends the speaker role (Greer, 2002; Greer & Ross, 2008; Skinner, 1957), which is to affect the listener, or in this case, the reader. One experimentally tested intervention from verbal behavior analysis is referred to as the writer immersion protocol and uses the natural cultural motivational operations of writing functions to expand or induce the functional and improve the structural components of writing (Helou, Lai, & Sterkin, 2007; Greer & Ross, 2008; Jodlowski, 2000; Madho, 1997; Reilly-Lawson & Greer, 2006; Visalli-Gold, 2005). Writer immersion is a tactic during which all communications are done in writing and the writer is required to affect the behavior of the reader as a measure of effective writing (Greer, 2002; Greer & Ross, 2008). Other writing curricula are devoted to the structural components of writing, which are usually, but not limited to, spelling, punctuation, grammar, capitalization, and sentence structures. However, in addition to learning the structure of writing, students also need to learn the *function* of writing, which is to affect the behavior of the reader (Greer, 2002). In order to affect the behavior of a reader, a writer must write such that a reader can accomplish the writer's intent. That is the writer must construct an algorithm that results in a reader accurately following the algorithm. In the verbal behavior approach and its historical precedent (Dewey, 1910) the structure of writing needs to be driven by the function.

During writer immersion, teachers and students in the classroom are not allowed to vocally communicate, they must write to one another instead. This can create the motivating operation (Michael, 1982, 2000, 2004) or the need-to-write; in order for the student to obtain the desired outcome. The student is required to write such that a reader can deliver the specified reinforcer. For example, if a student needs an eraser, he has to write "Can I have an eraser please?" and wait for the teacher to respond in writing, "Yes you may," or to give the student the eraser (Reilly-Lawson & Greer, 2005).

The other component of the protocol includes delivering instruction that meets the criterion for learn units (Emurian, 2004; Emurian, Hu, & Durham, 2000) in the context of writing a set of directions to a task, and having a peer read the written directions and attempt to follow them. The procedure is continued until the peer reader accomplishes the task. In order for the peer reader to correctly accomplish the task, the writer has to ensure her writing structures are accurate and her writing can function to change the behaviors of the peer reader. The writer edits and rewrites his or her instructions until the reader can accurately follow them (Reilly-Lawson & Greer, 2005). To increase the probability that a motivating operation is in place, recent studies have added the peer-yoked contingency component. The peer-yoked contingency component can be implemented during writer immersion in which both the writer and the peer reader win a point or a reinforcer once the peer reader has accomplished the task successfully; hence, the writer and the reader are yoked to a common reinforcer (Helou, et al., 2007).

Several studies showed that the implementation of a variety of writer immersion tactics resulted in increases in the structural and functional writing skills of the participants (Helou, et al., 2007; Jodlowski, 2000; Madho, 1997; Reilly-Lawson & Greer, 2006; Visalli-Gold, 2005). Madho (1997), for example, had participants write a set of directions for a peer to follow. Rewriting and corrections were implemented until the participants were able to write a set of directions that the peer can follow correctly without revisions. Several writer immersion studies also tested the effects of having a peer serving as peer editors or observing the peers receiving learn units. Jodlowski (2000) tested the effects of peer editing, teacher editing, and serving as a peer editor on student self-editing behavior. In three experiments, the experimenter tested the different components together and separately and found that students who served as a peer editor required fewer corrections to rewrite their essays versus when they only rewrote their essays. Visalli-Gold (2005) conducted two experiments to test the effects of receiving corrections and editing from a teacher versus observing peers receiving corrections and edits on untaught grammatical and structural components of students' writing. The results showed that the participants who observed their peers receiving learn units also improved in their functional writing responses.

Reilly-Lawson and Greer (2006) and Helou et al. (2007) conducted several experiments to further test the effects of writer immersion and self-editing on the structural and functional components of writing with middle school students diagnosed with emotional and behavior disorders. The results showed that editing the participants' writing, along with a yoked peer contingency component, improved the structural components and functional components of writing across all participants.

Even though studies on writer immersion showed functional effects on the structural and functional components of writing, there has been no research conducted on the effectiveness of the procedure or its components on writing mathematically and on solving problems as a function of reading algorithms. One possible application is writing mathematical algorithms or writing to explain how one is able to solve a certain problem. Mathematical algorithms are rules, written verbal stimuli, of arithmetic that include addition, subtraction, multiplication, division, extraction of roots, duplication, mediation, and regression (Reese, 1992). Although

Table 1. Components and procedures of a CABAS® AIL classroom

Components and instructional procedures
a) Learn unit (direct and observed)
b) Model demonstration learn units for more advanced students with observational learning (model of how to do the problem followed by probes and learn units)
c) Rule posting and reinforcement for following rules
d) Point system (individual, small group, and whole classroom) for accuracy and social behavior
e) Class wide peer tutoring
f) Differentiated instruction by small groups across all academic areas
g) Choral responding in small or large groups
h) Response board responding
i) Mastery objectives followed by fluency objectives
j) Personalized System of Instruction (PSI) for advanced students (Keller, 1968)
k) The use of book reports to assess students' reading comprehension skills. (The book reports included a summary of events of a story including the beginning, middle, and end, description of characters, and description of story setting)
l) Public posting of responses to math facts fluency, reading scores, correct completion of book reports, and class-wide learning data
m) CABAS® AIL decision protocol for when interventions are needed and where to locate the source of the learning problem
n) Use of Learning Pictures on a web server (showing mastery of objectives in the curricula and numbers of learn units needed to achieve mastery or fluency)

students may be able to follow algorithms to solve problems (Keohane & Greer, 2005; Marsico, 1998) students may not necessarily be able to *write* algorithms. The following of algorithms has been identified by the verbal behavior community as verbally-governed behavior, which is any behavior under the control of verbal stimuli (Glenn, 1987; Greer, 2002; Skinner, 1957; Vargas, 1998). Research on verbally governed behaviors has focused on following rules or the consequences that maintain or increase the frequency of verbally-governed behaviors (Ayllon & Azrin, 1964; Catania, Matthews, & Schimoff, 1982; Catania, Shimoff, & Matthews, 1989; Matthews, Catania, & Schimoff, 1985; Matthews, Shimoff, Catania, & Sagvolden, 1977; Shimoff, Catania, & Matthews, 1981; Vaughan, 1989; Verplanck, 1992). Research on *verbally-governing* behaviors has been limited to the writer immersion protocol for language arts or the emission of speech to affect the behavior of listeners (Greer & Ross, 2008). There is a lack of research on writing in mathematics, in particular in writing mathematical algorithms that we have identified as verbally governing behavior (instead of verbally-governed behavior).

Based on the results of writer immersion and yoked-peer contingency procedures on the increases in functional and structural components of writing, we wanted to test the effects of the procedure on writing mathematical algorithms. The current study sought to answer the following research questions: Will the use of a peer-yoked functional writing procedure, in which the writer observes the effects of their writing on a reader's behaviors, result in increases in the functional and structural components of students' written algorithms? Will the peer readers also learn to write functional algorithms after they observe their peers' written algorithms?

» METHOD

Participants

There were 6 participants (3 writers and 3 peer readers) selected for this study. All of the participants were 2nd grade students enrolled in an Accelerated Independent Learner (AIL) classroom (Greer, 2010) where all instruction is based on scientific procedures and student responses are continuously measured. The participants were selected from a second-grade classroom located in a metropolitan city. The public charter school was located in an urban setting and all of the students in the classroom received free lunch. There were 19 students in the classroom, 18 students were African-American and 1 student was Hispanic.

The components of the AIL model include the use of data collection and graphs to make moment-to-moment educational decisions and the implementation of educational tactics and protocols to increase learning outcomes. The classroom also implemented a token economy system in which students received plastic coins that could be exchanged for backup reinforcers. A group contingency was also implemented in which the students' groups in the classroom could earn points for a 10-minute free time at the end of the day. A class-wide contingency was implemented in which the whole class could earn a celebration for following directions, walking quietly in the hallway, or for completing classroom work. See Table 1 for the components of a CABAS® AIL classroom and instructional procedures implemented in the classroom (Greer, 2010).

The participants were selected because they were at or above grade level in reading, as measured using the *Developmental Reading Assessment, 2nd Edition* (DRA2). Thirteen out of 19 students in the classroom were at or above grade level in reading and mathematics. The DRA2 was one reading assessment used in the classroom and the students in the school were tested every 6–8 weeks. The students' DRA2 scores ranged from Level 16 to Level 36, or the grade equivalent of first to third grade reading levels. The participants selected for this study had already achieved the 2nd grade benchmark according to the DRA2; hence, the participants had grade level or higher fluency for textual responding and reading comprehension. All of the participants were also able to add and subtract basic math facts and they were proficient mathematically. This was indicated by their unit chapter tests in which the participants were performing at or above the grade standards.

The six participants were paired into groups of 2, Participants A (writer) and D (peer reader), Participants B (writer) and E (peer reader), and Participants C (writer) and F (peer reader). All of the participants completed pre-experimental and post-experimental probes for the dependent variable measures. The participants' verbal repertoires and capabilities (Greer & Ross, 2008) as well as their DRA2 test scores are shown in Table 2.

Setting and materials

All probe and experimental sessions were conducted in the classroom. In the center of the room were four groups of four to six desks per group. The classroom library and leisure area were located in the far end of the classroom by the windows. All sessions were conducted at a U-shaped table that was placed in a separate area of the classroom. The table was at the back of the room, adjacent to the classroom library. The table was normally

Table 2. Participants verbal repertoires (Greer & Ross, 2008) and DRA2 score

Participant	Age	Verbal cusps and capabilities in repertoire	DRA2 score and grade equivalent
A (writer)	8	Reader/Writer/Emerging Self-Editor Listener half of Naming Textual Responding at 120 wpm for 2nd-grade level text Transformation of stimulus function across saying and writing	DRA2 level 28 GE: 2
B (writer)	8	Reader/Writer Listener half of Naming Observational Learning Textual Responding at 120 wpm for 2nd-grade level text Transformation of stimulus function across saying and writing	DRA2 level 28 GE: 2
C (writer)	7	Reader/Writer/Emerging Self-Editor Listener half of Naming Observational Learning Textual Responding at 145 wpm for 2nd-grade level text Transformation of stimulus function across saying and writing	DRA2 level 28 GE: 2
D (peer reader)	8	Reader/Writer Full Naming Observational Learning Textual Responding at 150 wpm for 3rd -grade level text Transformation of stimulus function across saying and writing	DRA2 level 34 GE: 3
E (peer reader)	8	Reader/Writer/Emerging Self-Editor Full Naming Observational Learning Textual Responding at 120 wpm for 2nd-grade level text Transformation of stimulus function across saying and writing	DRA2 level 28 GE: 2
F (peer reader)	8	Reader/Writer/Emerging Self-Editor Listener half of Naming Observational Learning Textual Responding at 120 wpm for 3rd -grade level text Transformation of stimulus function across saying and writing	DRA2 level 36 GE: 3

Note. DRA2 = Developmental Reading Assessment® 2nd Edition; GE = grade equivalent.

used for small group instruction and the participants sat on the outer end of the table, with the experimenter sitting across the participants at the inner part of the U-shaped table. Other students in the classroom were engaged in regular instruction with teacher assistants during the study.

The materials used in this study were pencils and writing paper for each participant to write the algorithms and to solve word problems. All problems were presented on paper and probe questions were typed using Comic Sans 14 pt. font size. Word problems during training sessions were typed or handwritten. The types of problems included change, combine, equalize, and compare problems. Change and combine problems are problems that involve addition whereas equalize and compare problems are problems that involve subtraction. See Table 3 for an example of the word problems used during experimental probe and training sessions.

Dependent variables and response definitions

There were several variables measured in this experiment. All of the dependent variables were measured during pre and post intervention probe sessions. The first dependent variable was the functionality of the written algorithms, the second dependent variable was the number of correct responses to probe questions, and the third dependent variable was the accuracy of the structural components of the written algorithms. All participants (writers and peer readers) completed the experimental probes. The unconsequated probes consisted of four types of problems, two exemplars of each type, with a total of eight problems. The four problem types included change, combine, compare, and equalize problems (Jordan & Hanich, 2000). Multiple questions were presented in which the participants were asked to write the steps they need to solve the problem. The problems presented during the pre- and post-experimental probe sessions were similar in structure to those used in the intervention sessions, however, the specific language and numbers were different.

Table 3. Examples of story problems as presented by Jordan and Hanich (2000)

Type of problems
Change problems 1) Alex had 7 pennies. Then Bethany gave him 2 more pennies. How many pennies does Alex have now? 2) Carol had 8 pennies. Then Doug gave her some more pennies. Now Carol has 12 pennies. How many pennies did Doug give her?
Combine problems 1) Emily has 7 pennies. Farrah has 6 pennies. How many pennies do they have altogether? 2) Gina and Haley have 12 pennies together. Gina has 7 pennies. How many pennies does Haley have?
Compare problems 1) Ian has 10 pennies. Joan has 5 pennies. How many pennies does Ian have more than Joan? 2) Karl has 9 pennies. Lisa has 4 pennies. How many pennies does Lisa have less than Karl?
Equalize problems 1) Max has 12 pennies. Noah has 10 pennies. How many pennies does Noah need to have as many as Max? 2) Oliver has 5 pennies. Petra has 10 pennies. What could Oliver do to have as many pennies as Petra?

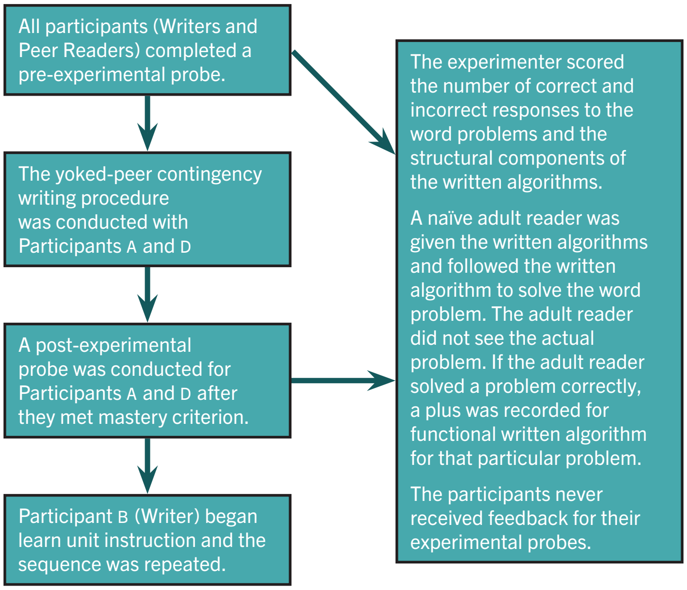

Figure 1. Flowchart of experimental sequence

During the experimental probe sessions, the participants (writers or peer readers) sat across from the experimenter and were given the direction, "Please complete the problems and try your best. If you do not know how to solve a problem, you cannot ask for help, just skip the question or write 'I don't know.'" The experimenter put the written problems in front of the participants and said "Go" to indicate the start of the probe session. Underneath each problem, the experimenter also asked the participants to write the steps on how to solve the problem; therefore, the participants had to solve the problem and write the steps (the algorithm). The experimenter delivered tokens throughout the probe session contingent upon participation to reinforce the participants for completing the problems. Tokens were not delivered contingent on correct responses, they were delivered contingent upon the participants engaging in the task. After the participants (writers and peer readers) completed the problems, the experimenter collected the papers, delivered more tokens, and told the participants to go back to their seats. The experimenter scored each paper after all participants were finished and did not provide feedback to the participants. The response definitions for the dependent variables are presented below.

Functionality of the written algorithms. A written algorithm was defined as functional if another adult naive reader was able to solve a word problem by following the written algorithm. During the experimental probe sessions, the participants (writers and peer readers) wrote algorithms to solve each of the eight word problems presented. A naive adult reader was given the written algorithm without seeing the actual problem and attempted to solve the problem based on the written algorithm. The readers functioned as observers who were naïve to the conditions of the experiment. If the reader solved the problem correctly, a plus was recorded for that particular problem. If the reader did not solve the problem correctly, a minus was recorded. The total possible number of correct responses was 8 for each participant.

Number of correct responses to word problems. A second dependent variable was the number of correct responses to word problems presented during the experimental probe sessions, solved by the writers and peer readers. A correct response was defined as the correct solution to a problem. An incorrect response was defined as an incorrect solution to a problem or if the participant did not write any answer to a problem. The total possible correct responses were eight.

Structural components of the written algorithms. The structural components of the written algorithms were the percent of correct punctuation marks, the percent of correct words spelled, the percent of correct words capitalized, and the percent of correct grammar usage. Except for the number of words written, all other structural components were counted based on the total number of sentences. For example, if the participant wrote three sentences, the structural components were scored out of three for one problem. The total number of possible responses varied depending on the number of sentences written for each problem. The number of correct responses was converted into percentages.

Experimental design and procedures

The design of the study was a delayed pre- and post-probe design to control for maturation and instructional history. All of the participants (writers and peer readers) received a pre-experimental probe at the onset of the study. A pilot study with three different writers showed that all of the participants were able to solve the word problems but they were not able to write about the word problems. In this study, Participant A (writer) received the intervention procedure along with Participant D (peer reader). None of the peer readers received the writing intervention. After Participant A (writer) met mastery criterion during the intervention, both Participant A (writer) and Participant D (peer reader) completed a post-experimental probe. Intervention then began for Participant B (writer) and Participant E (peer reader) as the peer confederate. Please see Figure 1 for a flowchart of the experimental sequence. The post-probe was delivered between three to four weeks after the pre-probe was conducted.

Independent variable: a peer-yoked functional writing procedure

Prior to the onset of the functional writing intervention the experimenter sat with the writer and the peer reader (for example, with Participants A and D) and showed the participants the game board. The board game consisted of five spaces on the left for the participant and the peer reader, and five spaces on the right for the experimenter. At the top of the game board, the name or picture of a reinforcer was written and taped to the board.

The experimenter said, "We are going to play a game. You will be on a team together and you're playing against me. The winner of the game will earn (reinforcer). The game will be about math. "_____" (writer's name) will write some directions and if "_____" (peer reader's name) can solve the problem correctly, your team will move up on one step on the game board. If "_____" (peer reader's name) gets a wrong answer, I will move up one space on the game board." The experimenter then asked the peer reader to go back to his or her seat and the experimenter continued with the writer.

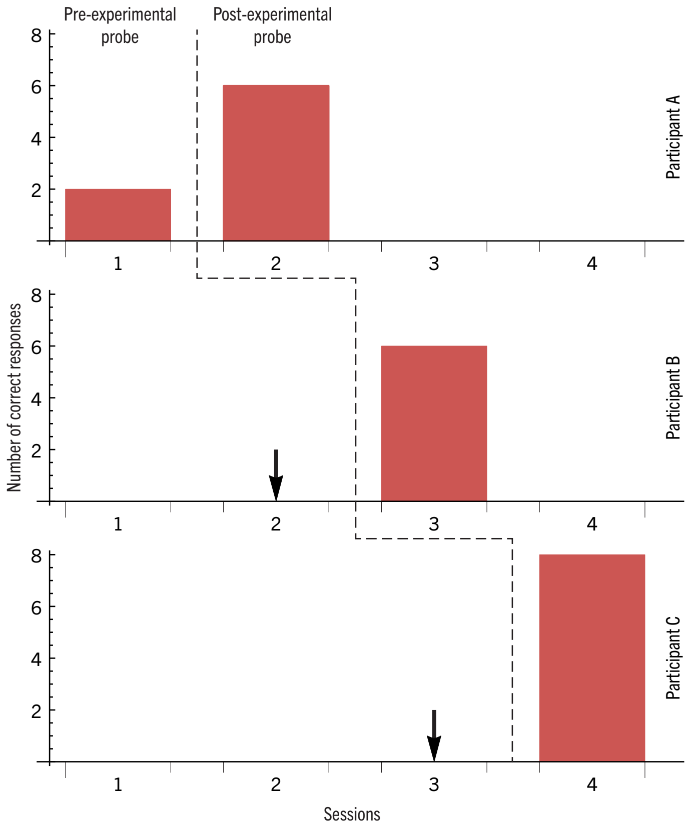

Figure 2. The number of correct problems solved by a naïve adult reader as a function of verbally governing algorithms written by Participants A, B, and C (Writers) during experimental probe sessions.

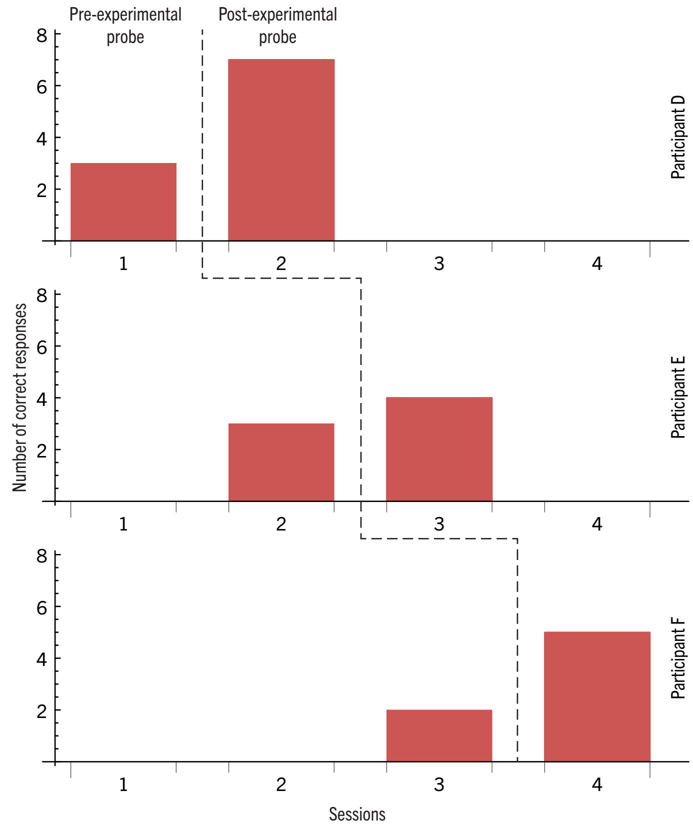

Figure 3. The number of correct problems solved by a naïve adult reader as a function of verbally governing algorithms written by Participants D, E, and F (Peer readers) during experimental probe sessions.

During each session, the writer sat with the experimenter and the experimenter gave the writer a word problem to solve. If the writer solved the word problem correctly, the experimenter delivered reinforcement (i.e. praise) and asked the writer to write the algorithm telling "_____" (peer's name) how to solve that word problem on a different piece of paper. The experimenter asked the writer to solve the word problem first to ensure he or she was able to solve the problem correctly before writing *about* the problem. If the writer did not solve the word problem correctly, the experimenter delivered a correction by telling the participant how to solve the problem correctly and gave the writer another word problem to solve that was similar in structure.

After the writer responded to a problem correctly, then the experimenter asked the writer to write the algorithm to solve the word problem. The word problems presented during the procedure involved using manipulatives (blocks). Through the use of manipulatives, the writer was able to observe the component steps performed by the peer reader. After the writer wrote the algorithm, the experimenter corrected the spelling, punctuation, and capitalization of the algorithm. This was done by showing the writer what the correct spelling, punctuation, and capitalization should be and asked the writer to rewrite the algorithm with the corrections. The algorithm was given to the peer reader to follow. The experimenter only corrected the structure and not the content or the functionality of the algorithm.

The peer reader then attempted to solve the problem using the algorithm provided while the writer sat next to the peer reader. The peer reader did not see the question and only followed the directions given by the writer. The peer reader read the algorithm out loud and used the blocks to solve the problem. For example, if the participant wrote "First take 16 blocks," then the peer reader took out 16 blocks. The next step in the algorithm may have been, "Then take seven more blocks," and the peer reader did so. The participant had to write another step to solve the problem, for example, "Now add them all up and you have the answer."

The writer met mastery criterion for the procedure when the peer reader was able to solve the word problem at 100% accuracy for five different problems. If the peer reader was not able to solve the word problem correctly the first time, the writer rewrote his or her algorithm until the peer reader was able to complete the word problem correctly. If the peer reader was not able to solve the problem correctly the first time, the experimenter moved up a space on the game board. However the writer and the peer reader could only advance on the game board if the problem was solved correctly on the first opportunity.

The sequence of steps is as follows: 1) a writer completed a word problem and wrote the algorithm of how to complete the problem out of view of the peer reader, 2) the experimenter delivered corrections for the capitalization, spelling, and punctuation of the written algorithm, 3) the writer corrected his or her errors

Table 4. Number of correct word problems solved by the writers during pre-experimental and post-experimental probe sessions

Participant	Pre-experimental probe	Post-experimental probe
A	7/8	7/8
B	4/8	8/8
C	5/8	7/8

Table 5. Number of correct word problems solved by the peer readers during pre-experimental and post-experimental probe sessions

Participant	Pre-experimental probe	Post-experimental probe
D	6/8	8/8
E	7/8	7/8
F	2/8	5/8

and rewrote the steps, and 4) the experimenter gave the written algorithm to a peer reader who read the steps, while sitting next to the writer, and attempted to solve the problem based on the written algorithm by using blocks. The actual problem was hidden from the peer reader. This was done to eliminate the possibility that the peer reader might be able to solve the problem just from reading the word problem. If the peer reader was able to solve the problem correctly, the writer and the peer reader moved up one space on the game board. If the peer reader was not able to solve the problem correctly the first time, the experimenter moved one up on the game board. If the writer and the peer reader were able to move five spaces on the game board, they both earned a reinforcer.

Interscorer agreement

A second independent observer provided interscorer agreement. For Participant A (writer), IOA was calculated for 100% of probe sessions, with 100% agreement for the number of words written and 100% agreement for the structural components. IOA was also calculated for the training sessions, in which a second observer scored the participants' written algorithms for functionality or if the peer reader solved the problem correctly. IOA for Participant A was conducted for 100% of training sessions, with 100% agreement on each of the three measures.

For Participant B (writer), IOA was calculated for 50% of probe sessions, with 100% agreement for the number of words written and 100% agreement for the structural components. IOA for Participant B was conducted for 100% of training sessions, with 100% agreement. For Participant C (writer), IOA was calculated for 100% of probe sessions, with 100% agreement for the number of words written and the structural components. IOA was also calculated for 100% of training sessions with 100% agreement.

For Participant D (peer reader), IOA was calculated for 100% of probe sessions, with 100% agreement for the number of words written and a mean of 96% agreement for the structural components (range 88%–100% agreement). For Participant E (peer reader), IOA was calculated for 100% of probe sessions, with 100% agreement for the number of words written and a mean of 96% agreement for the structural components (88%–100% agreement). For Participant F (peer reader), IOA was calculated for 50% of probe sessions, with 100% agreement for the number of words written and 100% agreement for the structural components.

Data collection

For the dependent variables, if the adult reader solved the problem correctly, a plus (+) was recorded. If the adult reader did not solve the problem correctly, a minus (–) was recorded. The total number of possible correct responses was eight. Data were presented as the number of correct responses. The participants' responses to the word problems were also scored. If the participant solved a word problem correctly, a plus (+) was recorded. If the participant did not solve a word problem correctly, a minus (–) was recorded. Data were presented as the number of correct responses. For the written algorithms, the number of words written was counted, recorded, and reported as number of words written. The numbers of correct and incorrect spelling, punctuation, and capitalization were calculated based on the total number of sentences and converted into percent correct.

For the independent variable, during learn unit instruction a plus (+) was recorded for correct responses and a minus (–) was recorded for incorrect responses. The number of rewrites during the peer-yoked contingency procedure was also recorded and reported as the number of rewrites for each word problem. The structural components of the written algorithms during the procedure were counted, recorded, and converted into percentages.

Table 6. The number of rewrites by the writers for each problem during the procedure

Participant	Problem	(Type)	Rewrites
A	1	(Change)	0
	2	(Combine)	0
	3	(Compare)	1
	4	(Equalize)	3
	5	(Change)	0
	6	(Compare)	1
	7	(Combine)	0
	8	(Equalize)	0
B	1	(Compare)	3
	2	(Change)	0
	3	(Combine)	0
	4	(Equalize)	1
	5	(Change)	0
	6	(Combine)	0
	7	(Compare)	0
C	1	(Combine)	2
	2	(Compare)	1
	3	(Change)	0
	4	(Equalize)	3
	5	(Change)	0
	6	(Combine)	0
	7	(Equalize)	1
	8	(Compare)	1
	9	(Combine)	0
	10	(Change)	0
	11	(Equalize)	0
	12	(Compare)	1
	13	(Change)	0
	14	(Equalize)	0

» RESULTS

The results for the number of word problems solved by a naïve adult reader for the probes showed that for all six participants there was an increase in the number of correct responses by a reader who followed the written algorithms to solve the word problems presented in probe sessions. Figures 2 and 3 show the delayed pre- and post-probe design testing the effect of the peer-yoked contingency writing protocol on the functional effects of the written algorithms. For Participant A (writer), the number of word problems solved correctly by a naïve reader increased from two to six following the intervention procedure. For Participants B (writer) and C (writer), the number of word problems solved correctly by a naïve reader increased from zero to six and zero to eight, respectively. For Participants D (peer reader), the number of word problems solved correctly by a naïve reader increased from three to seven. For Participant E (peer reader), the number of word problems solved increased from three to five, and for Participant F (peer reader) the number increased from two to five. The latter two participants showed less of an effect.

Participant A (writer) was able to solve the word problems with seven correct responses out of eight prior to the implementation of the peer-yoked functional writing procedure. The number of correct responses remained the same after the implementation of the procedure. For Participant B (writer), the number of correct responses to the word problems increased from four correct to eight correct responses. For Participant C (writer), the number of correct responses increased from five to seven correct responses. Participant D's (peer reader) number of correct responses increased from six to eight correct responses. Participant E's (peer reader) number of correct responses remained the same; she had seven correct responses. For Participant F (peer reader), the number of correct responses increased from two to five correct responses. See Tables 4 and 5 for the number of correct responses during the pre-experimental and post-experimental probes for all participants.

There were several measures for the structural components of the written algorithms. The structural components were punctuation, capitalization, spelling, and grammar. Data were recorded as the number of correct components for every sentence, and the total number of correct components was calculated into a percentage. The results showed an increase in the structural components across the participant writers. There were mixed results for the peer readers; some of the percent correct structural components remained the same or decreased for one participant. Figures 4 and 5 show the percent correct of the structural components of the written algorithms.

During the intervention procedure, the participants had to write revisions based on the responses of the reader. Table 6 shows the number of algorithms the participants completed, the type of word problems, and the number of revisions required.

» DISCUSSION

In this experiment, the results demonstrated a functional relation between the functional writing procedure with yoked-contingency game board and the number of correct functional and structural components for all three writers. None of the writers were able

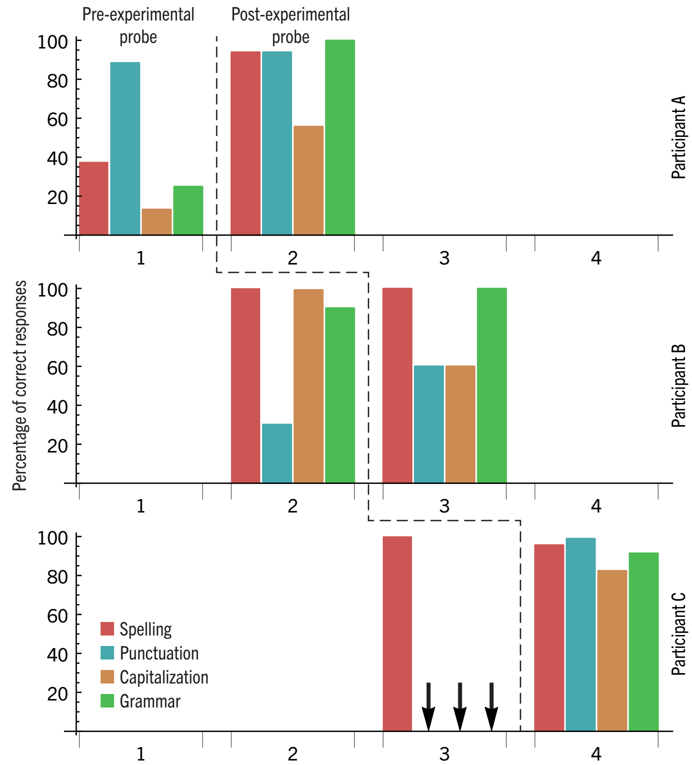

Figure 4. Percent of correct structural components in the algorithms written by Participants A, B, and C (Writers).

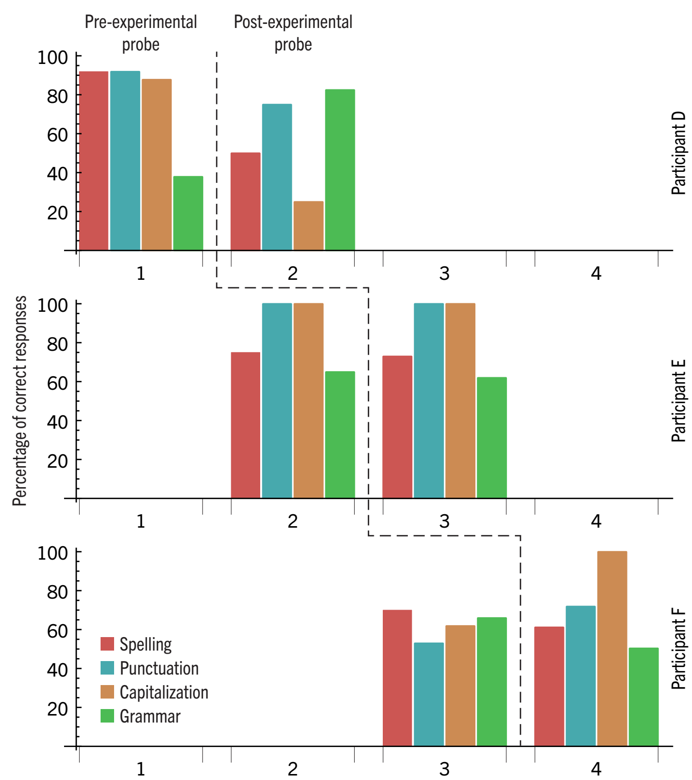

Figure 5. Percent of correct structural components in the algorithms written by Participants D, E, and F (Peer Readers).

to write functional algorithms in the beginning of the study, and after the implementation of the writing procedure they were able to write at least six functional algorithms out of the eight total opportunities. This result is consistent with other writer immersion studies, in which the participants learned to write essays that affected the readers (Helou, Lai, & Sterkin, 2007; Jodlowski, 2000; Madho, 1997; Reilly-Lawson & Greer, 2006; Visalli-Gold, 2005). The percent correct of the structural components for the writers improved after the implementation of the procedure, whereas the percent correct remained the same or decreased for the peer readers. This could be explained by the learn units the writers received during the intervention procedure that resulted in the improvements of the structural components, whereas the peer readers never received feedback on their written algorithms during the experimental probe sessions.

There were possible explanations for the results obtained. One possible explanation for the effects of the functional writing procedure on the increase of the functional written algorithms is the use of establishing operations in the procedure. As with other writer immersion studies, the role of the establishing operation is key to learning the function of writing which is to affect the behavior of the reader (Greer & Ross, 2008). The writing procedure created a natural motivational condition for the writers to write functional algorithms and the use of the game board, or the yoked-peer contingency, enhanced that motivational condition. The writer had to write functional algorithms in order for his or her peer to respond correctly to the word problem while at the same time, the writer and the peer need to work together in order to obtain the reinforcer (Davies-Lackey, 2005; Stolfi, 2005).

Another possible explanation was the presence of the audience in the tasks. The use of audience seems to improve students' writing even though most students believe that they eventually write for their teacher (Applebee, 1981, 1984; Bull, 1990; Gilbert, 1989; Long, 1990). In this experiment, the writers knew they were writing for their peers and they could observe the peer's responses immediately. The peer's behaviors then affected the behaviors of the writer in which they had to change the way they wrote in order for the peer to figure out the correct answer. The writers did not have to "imagine" their audience, they had an audience and this seemed to improve their writing. In one of the first studies on writer immersion, Madho (1997) found the effects of receiving responses from peers improved the target participant's writings, therefore the peer serves as an additional motivational condition in the yoked contingency as well as the target audience for the writers, and this combination may be the key component to effective writing procedures.

One interesting finding in this study was the effects of the procedure on the verbally governing responses of the peer readers. No other writer immersion studies tested the effects of the protocol on the responses of the peer readers and the results of this study showed that the peer readers could learn to write effectively and functionally by observing the responses of their peer writers. Visalli-Gold (2005) conducted a study to test the effects of the peers observing learn units presented to the target students and the effects on the structural components of writing; however, in this study the peers never observed the writers receiving learn units from the experimenter. The peer readers in this experiment participated as peer readers in a pilot study, therefore the peer readers were already familiar with the procedure. Nevertheless, the peer readers never received corrections in terms of the structural components. Jodlowski (2000) found that serving as a peer editor resulted in improvements in the peer editor's own writing as well as fewer number of learn units to write effective essays. In this study the peer readers did not edit the writing of their peer writers but they observed the *changes* in their peers' writing. This observation of the changes in the written algorithms could possibly have an effect on their own writing.

One possible explanation of the effect of observation was that the peer readers all had the observational learning capability in their repertoires which enabled them to learn through observing the consequences delivered to their peers (Davies-Lackey, 2005; Gautreaux, 2005; Greer & Ross, 2008; Greer, Singer-Dudek, & Gautreaux, 2006; Periera-Delgado, 2005; Rothstein & Gautreax, 2007; Reilly-Lawson & Walsh, 2007; Stolfi, 2005; Walsh, 2009). In this study the peer readers did not observe the learn units delivered to the writers, however they observed the changes in the peer's writing and the consequences delivered after the writers made the changes. If the writer did not write a functional algorithm, the peer reader could not solve the problem correctly. Nevertheless, after the writer edited his or her written algorithm, the peer reader was then able to solve the problem.

The results also showed that being able to solve word problems did not result in the ability to write about the word problems, which demonstrated the difference between procedural and conceptual knowledge (Miller, 1983 as cited by Reese, 1989). The participants in this study were able to solve the word problems with accuracy (verbally governed responses) however they were not able to write about the problems (verbally governing responses). It could be that verbally governed responses (or following an algorithm) are similar to listener responses, whereas verbally governing responses (writing about the algorithm) are similar to speaker responses. Reading is an extension of the listener behavior, and following verbally governed algorithms may be a similar type of listener behavior. On the other hand, writing is an extension of the speaker response, therefore producing verbally governing responses may be a type of writing behavior. Greer and Speckman (2009) stated that initially the listener and speaker responses are separate; however, they have identified the "joining" of the two responses as a necessary developmental capability in order for students to advance to more complex repertoires. If verbally governed responses and verbally governing responses are indeed similar to listener and speaker responses, it may be that students need to be taught both in order for the joining to occur.

One limitation in this study was the lack of measurement of the component steps of the written algorithms. Each algorithm was measured as either a correct or incorrect response; however, we did not measure the number of correct and incorrect steps in each algorithm. By measuring each step of the algorithm we could have a better picture in terms of the components of each algorithm and as the students write more complex algorithms breaking down the algorithm into component steps may be necessary.

Another limitation in this study was the level of difficulty of the problems. Some of the writers only needed on average, one rewrite in the procedure, especially for questions that consisted of addition problems. Students learn through the learn unit and receiving corrections through rewriting (Jodlowski, 2000; Madho, 1997; Reilly-Lawson & Greer, 2006; Visalli-Gold, 2005). In this study the writers learned quickly, from the first problem they encountered, what needed to be done in order for them to move up one space on the game board. Most of the writers had difficulty with compare and equalize problems and those were the problems that required two or more rewrites; however, there should have been more variations in the types of word problems as well as in the level of difficulty of the problems. Change and combine problems consist of problems that are addition problems whereas compare and equalize problems consist of subtraction problems. Although not all of the participants had difficulties with the compare and equalize problems, the errors occurred more often with these types of problems. This result is consistent with the findings by Hartlep and Golz (2009) that addition word problems are generally easier to solve than subtraction word problems.

An additional possible limitation to this study was that the peer readers only had to solve five word problems correctly before they could obtain the reinforcer. It is possible that the participants may not have had enough opportunities to respond to different types of word problems. Increasing the number of opportunities to respond would have led to more learning opportunities and the chance for the participants to receive more learn units (Greer, 2002; Greenwood & Delquadri, 1981).

A further limitation included the use of a pre- and post- probe design. It is possible that re-administering the probes could have had an effect on the increases in the functional and structural components of the written algorithms. We tried to minimize the effect by not providing the participants feedback on their written algorithms; that is, we did not provide reinforcement or correction and simply delivered reinforcement for participating in the study.

The findings of this study showed the effects of functional writing contingencies on verbally governing algorithms produced by typically developing second grade students. There is a great need for students to be able to write across curricular areas and even though the "writing-to-learn movement" and procedures have shown promising results (Bangert-Drowns et al., 2004); there were no studies that demonstrated the direct effects of writing on the reader in the field of mathematics. The procedures implemented in this study used the establishing operation and the presence of an audience and they may be the key components in teaching students to produce effective writing in mathematics (Greer & Ross, 2008; Helou et al., 2007). The observational learning capability was also a key component in writing effectively. In the classroom, this procedure could easily be implemented in small groups and the use of a board game could function as a motivational component for the students to write. Students could compete with one another or with the teacher, and not only would the students observe the effects of their writing immediately they would also be motivated to write and work together with their peers. In prior studies the researchers have avoided students competing with other students to presumably advance students' positive social interactions with each other. This has been identified to be beneficial as a component of the social listener protocol that has resulted in more social conversation between children diagnosed with Autism Spectrum Disorder (Reilly-Lawson & Walsh, 2007). However, this may or may not be the case with typically developing children and is also a topic for future research. This study contributes both to the field of applied behavior analysis and the field of teaching by providing a measurable and effective method to teach writing in mathematics. It also contributes to our basic understanding of verbal behavior development in that the effects of a functional writing intervention points to the verbal nature of mathematics, suggesting that verbal development needs to incorporate the verbal behavior components of mathematics education. ■

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