A Functional Analysis of Stimulus Control Strengths of Antecedents and Consequences in Learning

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Abstract

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We analyzed the contribution to the stimulus control in learning from the antecedents and the contingent consequences in this research. In the first experiment, we analyzed the stimulus control strengths of the preferred visual antecedent targets and prosthetic reinforcers in skill acquisition. The preferred- (PA) and non-preferred-visual-antecedent-stimuli (NA) were paired with two contingent consequences. In the conditions paired with the consequence of praise-for-correct-response (PC), researchers praised correct responses and implemented a correction procedure contingent on incorrect responses. In the conditions paired with the math-for-correct-response (MC), the procedure was the same except that a correct response was followed by presenting a non-preferred activity of doing a math problem. We measured the acquisition rates and maintenance of responses of PA and NA across the two consequence conditions. The results showed that all participants acquired the PA faster regardless of the consequence conditions. The findings suggest that the see-say correspondence of the PA may function as a stronger reinforcer in skill acquisition than the contingent consequence of prosthetic reinforcer delivered by the instructor. In the second experiment we controlled the reinforcement from the antecedent stimuli and conducted a component analysis of skill acquisition consequences. In the learn unit (LU) condition, researchers praised correct responses and implemented a correction procedure contingent on incorrect responses. In the praise-only-for-correct-responses (PC) condition, researchers delivered contingent praise for correct responses and ignored incorrect responses. In the correction-only-for-incorrect-responses (CI) condition, researchers ignored correct responses and implemented the correction procedure contingent on incorrect responses. We manipulated this independent variable across educational and abstract stimuli and measured acquisition rate, duration, and maintenance of responses. The results showed that the LU and CI conditions were both effective on teaching listener responses and were more effective than the PC procedure. The results suggested that the correction procedure was probably necessary and sufficient for skill acquisition and maintenance. Since the stimulus set sizes in the previous experiments were randomly decided, in the third experiment we conducted a systematic replication of Kodak et al.'s (2020) and Vladescu et al.'s (2021) research on the effects of stimulus set sizes on skill acquisition. We manipulated the stimulus set sizes by teaching three, six, and 12 sight words simultaneously during learn unit instruction. Researchers taught participants until the participant's responding reached the acquisition criterion for 12 different sight words per set size condition. The acquisition criterion was set for an individual operant, whereby when accuracy met criterion for a single sight word, that sight word was replaced in the following session. The results showed that the set-size-three was more efficient than the set-size-six and -twelve in acquisition, which were more consistent with Vladescu et al.'s findings, but not consistent with Kodak et al.'s findings. However, the set-size-twelve reliably produced the highest maintenance levels for all participants. The opposing acquisition and maintenance results suggest further discussion on the definition of "effectiveness" in learning. To sum up, the results of these studies demonstrated that the strengths of stimulus control were a function of the synergistic reinforcement strengths across multiple correspondences of motivating operations, discriminative stimuli, and the contingent consequences.

Keywords: correction procedure, motivating operations, preferred visual antecedent stimuli, stimulus control, stimulus set size

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Chapter 1

Introduction and Review of the Literature

The level of academic competencies involving the academic skills, self-management behaviors, and academic interest is critical for students' future choices of majors and careers and would in turn affect their socioeconomic status after graduation from college (Betz & Hackett, 1983; National Science Board, 2006). The identification of the instructional procedures and components (e.g., the size and the reinforcement strength of antecedent stimuli and the components of contingent consequences) that establish high motivating conditions toward academic subjects would effectively facilitate learning and improve the academic achievement for students with and without developmental delays.

Considering that academic interest is a significant indicator for learning, researchers in the field of behavioral science and neuroscience identified different motivating variables that were related to academic achievement (Buttigieg & Greer, 2021; Gentilini & Greer, 2020, 2021; Greer, 2020; Hidi et al., 2004; Kidd & Hayden, 2015; Longano & Greer, 2006; Maurilus, 2018; Moore, 2017). According to neuroscience, "curiosity" is a motivator for learning that influenced decision-making as well as cognitive development (Kidd & Hayden, 2015). Specifically, "curiosity" establishes motivating conditions like deprivation, in which a cognitive deprivation was set up to close the gap in knowledge and understanding (Loewenstein, 1994). In comparison, radical behaviorists analyzed the motivating variables under multiple contingencies involving discriminative stimuli and reinforcers, such that the reinforcers are under the context control of the corresponding motivating conditions (Greer et al., 2017). The review of the literature reported herein first summarized and compared the perspectives of neuroscience and behavioral psychologies regarding the relation between motivation and academic achievement and identify instruction procedures and components (e.g., preferred and non-preferred visual antecedent stimuli, correction procedures, and the size of antecedent stimuli) that can effectively increase motivation and facilitate learning for students with and without development delays. I also postulated a framework that the strengths of stimulus control were a function of the synergistic reinforcement strengths across multiple correspondences between MOs and corresponding reinforcers based on the analysis of findings from the two approaches.

1.1 Perspectives of Neuroscience

Kidd and Hayden (2015) identified “curiosity” as a motivator for learning that influenced decision-making as well as cognitive development. Curiosity refers to a process of information-seeking that involves a variety of phenomena such as play, exploration, reinforcement learning, latent learning, neophilia, and self-reported desire for information (Deci, 1975; Gruber et al., 2014; Jirout & Klahr, 2012; Kang et al., 2009; Sutton & Barto, 1998). In other words, curiosity is the desire to understand what you know that you do not (Kidd & Hayden, 2016).

Loewenstein (1994) further assimilated curiosity to motivating conditions of deprivation, in which a cognitive deprivation was set up to close the gap in knowledge and understanding. A small amount of information would increase curiosity, but satiation would occur when enough information was gained and in turn decrease the level of curiosity (Loewenstein, 1994). Kang et al. (2009) confirmed this theory and demonstrated that curiosity in solving a question was a U-shaped function of confidence with the solution. Students were least curious when they had no clue about the answer and when they were 100% confident with the answer. By comparison, students showed highest curiosity when they had certain clues about the answer but lacked confidence. The results also indicated that higher curiosity enhances learning in the sense that higher curiosity level led to higher performance in the assessment (Kang et al., 2009). Gureckis and Markant (2012) pinpointed the role of curiosity in improving learning as gaining adherents so that students could devote efforts to acquire useful information that they did not yet possess.

According to Daw et al. (2006), the frontopolar cortex and intraparietal sulcus were significantly more active during exploration, whereas striatum and ventromedial prefrontal cortex (vmPFC) were more active during exploitative choices. Pearson et al. (2011) verified past findings and showed that the posterior cingulate cortex (PCC) has greater tonic firing rates on exploratory trials than on exploitative trials. Since these aforementioned areas were all related to canonical reward areas and learning areas in the brain, curiosity might link to the reward system and learning process (Heilbronner & Platt, 2013; Kidd & Hayden, 2015). Additionally, Wittmann et al. (2008) tested the role of exploration in curiosity using the “four-arm bandit” task, in which participants were required to choose repetitively between four slot machines with different explorative (i.e., learning) and exploitive (i.e., performance) potentials. Novel images were used to test the explorative potentials and familiar images the expoitive potentials. The results revealed that participants were more likely to choose novel images due to the “novelty bonus” (Gittins & Jones, 1974) exerted by these images. This novelty bonus increased the expected reward for the novel images, which increased the reward prediction error (RPE) signal in ventral striatum (Kidd & Hayden, 2015). Hence, exploration set up motivation provided by the brain's reward systems in learning. On the other hand, past research on monkeys showed that when the choice did not result in immediate reinforcement between gambles with identical probabilities (50/50) and payoffs (i.e., juice), they reliably chose the option with the immediate resolution of uncertainty (Blanchard et al., 2015; Bromberg-Martin & Hikosaka, 2009, 2011). Since the information whether the monkey won or lost the gamble was delivered after the choice making and could not improve choices, the immediate elimination of uncertainty may function as negative reinforcement and would in turn motivate learning. Considering that dopamine neurons signal critical reward-related cognition, Gruber et al. (2014) tested the effects of direct rewards (e.g., juice) and information seeking on dopamine neuron activity (DA). The results showed that dopamine neurons signaled both direct rewards and information, suggesting that acquisition of information also functioned as rewards in the learning process.

1.2 Perspectives of Behavioral Psychology

The studies from neuroscience identified that the cognitive factor of “curiosity” was positively correlated with the students’ learning rates (Gureckis & Markant, 2012; Hidi et al., 2004; Kidd & Hayden, 2015). Nevertheless, the lack of widely accepted definition and standardized laboratory tasks limited our understanding of the functional relationship between “curiosity” and learning (Kidd & Hayden, 2015). In comparison, past research under the behavior analytic perspective provided operational definitions of motivating operations and functional analysis of variables regarding the strength of stimulus control in learning. This section focused on examining the role of motivation in the analysis of stimulus control.

Stimulus Control

The “evolution” of human behavior is a series of small variations and selections by consequences similar to the plausibility as mirrored in evolution theory (Skinner, 1986). The evolution process begins with phylogenic signaling, in which the contingency is first established for imitation for survival value and then for the evolution of the reciprocal process of modeling. Ontogenic signaling forms later, in which the contingency for imitation is set up through reinforcement until the behavior comes under the stimulus control of gestures. Behavior, thus, is selected by the corresponding reinforcing consequences (Skinner, 1986). The selection processes involving variation, selection, and retention under evolutionary biology are functionally parallel to those under radical behaviorism, such that the former focuses on the group of organisms whereas the latter the individual organism (Donahoe, 2012). Stimulus control is not perfect given its dependence on the related environmental context (Skinner, 1938, p. 241). Although not delineated explicitly, the three-term contingency (i.e., discriminative stimuli, response, consequence) embodies both principles in the sense that the occurrence of the target behavior, and not any other behaviors, produces the particular reinforcing consequence only in the presence of a particular environmental state that involves discriminative stimuli (S^Ds) and other higher order relations among environment (Sidman, 2008).

Specifically, Skinner (1933) assimilated the processes of establishing antecedent stimulus control to the processes of extinction. Sidman (2008) argued against this hypothesis and supported the view of Ray (1969), such that the establishment of a new stimulus-response relation creates a new stimulus control topography with different strength under contextual control. Ray (1969) distinguished between the existence of a stimulus discrimination and the occurrence frequency of this discrimination. The strength of the established antecedent stimulus control topography would, as a result, affect the frequency of operant responses. In other words, stimulus discriminations do not extinguish but simply no longer receive reinforcement and in turn occur less often. Since the antecedent stimulus control topography would not disappear even when it did not result in reinforcement, the identification of the controlling antecedent stimuli could be extremely complex (Sidman, 2008). That is to say, "Stimulus control topography coherence refers to the degree of concordance between the stimulus properties specified as relevant by the individual arranging a reinforcement contingency … and the stimulus properties that come to control the behavior of the organism that experiences those contingencies" (McIlvane & Dube, 2003, p. 195). Complex contextual control affects the identification of the controlling antecedent stimuli.

Nevertheless, I argue that the theory of antecedent stimulus control topography did not contradict Skinner's (1957) hypothesis of extinction. Under the control of specified contextual stimuli (e.g., MOs), S^D gained the control over the target response whereas S-delta could not evoke this response (Skinner, 1957). However, in the presence of a different environmental context, this S-delta could still evoke the target response that was established before, if such behavior could result in the reinforcing consequence from the corresponding community (Greer, 2020). The processes of stimulus discrimination were parallel to those of extinction in the sense that under specific environment, S-delta could not lead to the access to the reinforcer. Skinner (1957) further clarified the processes of the establishment of antecedent stimulus control in the learning of "pyramid" in which the exposure to multiple exemplars of the pyramid sharpened the stimulus control. The learning processes involved reinforcement of target stimulus properties and lack of or punishment of negative stimulus properties. In other words, the reinforcing community refrained from reinforcing responses regarding irrelevant properties such as red or small objects, and on the other hand, consistently reinforced the responses of pyramids regardless of color, size, or other properties. Therefore, the antecedent stimulus control over novel responses is established and strengthened through the multiple exemplar experience including non-exemplars. This interpretation also resolves the problem of stimulus control coherence proposed by McIlvane and Dube (2003).

Relation between Motivating Operations and Stimulus Control

Although Skinner (1938, 1953) admitted the important role of contextual stimuli in evoking the target response under the three-term contingency, he did not define the function of this correspondence and instead resorted to procedural definitions to describe their effects on behavior (Edwards et al., 2019). Specifically, the time locus of the S^D acts as a filter: “if [the S^D] matches the field existing at the time of reinforcement, the rate of responding is maximal; if it does not, the rate is depressed” (Skinner, 1938, p. 229). The S^D sets the occasion for the emission of a target response such that the target response is evoked rather than elicited by the S^D if the reinforcer is available (Skinner, 1938). Nevertheless, the occurrence of the target behavior depends on “other factors” instead of the S^D once it is present (Skinner, 1938, p.241). These “other factors” refer to motivating operations (MOs) regarding the corresponding three-term contingencies (Whelan and Barnes-Holmes, 2010). MOs (i.e., establishing and abolishing operations) involve momentarily altering the reinforcing effectiveness of other events and/or the frequency of the occurrence of the target behavior followed by the corresponding reinforcers (Michael, 1982, p. 150 - 151). The concept of MOs allows further analysis of the evocative function of S^D s through the manipulation of the corresponding MOs. Specifically, MOs function generally to strengthen corresponding S^D s, such that the behavior-altering effects of MOs depend on the presence of corresponding S^D (Laraway et al., 2003; McDevitt & Fantino, 1993). Furthermore, MOs reliably alter the evocative function of S^D s and the degree of stimulus generalization (Lotfizadeh et al., 2012). The increase of MOs would increase the evocative function of relevant S^D s and stimulus generalization. Thus, the S^D functions as a mediator in the relation between MOs and responses.

The emission of a response might be the function of “multiple control” such that “(a) the strength of a single response may be, and usually is, a function of more than one variable and (b) a single variable usually affects more than one response” (Skinner, 1957, p. 227). Moreover, all behaviors are multiply controlled given that MOs are relevant to all operant behavior (Edwards et al., 2019). The term multiple-control infers that the emission of a target response might be controlled directly by the MO, directly by the S^D, or by a combination of the two without reflecting the interactive relationship between these two variables. Edwards et al. (2019), therefore, proposed a more parsimonious solution to analyze the role of MO in the three-term contingency, in which MO was defined as “operations that modulate the reinforcing or punishing effectiveness of particular kinds of events and the control of behavior by discriminative stimuli historically relevant to those events” (p. 1). This definition identified behavior- and function-altering effects of MOs as indirect effects and in turn deemphasized the distinction between these effects. Additionally, by incorporating the influences of MOs on discriminative stimuli into the MO definition, we could test the function of MOs without resorting to the complicated concepts of conditioned motivating operations (CMOs) proposed by Michael (1993). The problem of stimulus control coherence initiated by McIlvane and Dube (2003) could also be addressed more readily under this hypothesis. The strength of a target response in learning is multiply controlled by the compound strengths of corresponding MO-S^D-response-reinforcer relations.

1.3 A Hypothetical Framework

To simplify and clarify the role of motivating conditions in learning, I adopted the new definition of MOs proposed by Edwards et al. (2019) and attributed the influences of MOs on S^D to the MO definition. Nevertheless, I considered the reinforcement strength as a function of MO, S^D, Response, and Reinforcer, without distinguishing the contribution of the MO and reinforcer to the stimulus control under the same sub-contingency, following the rule of parsimony. The strength of stimulus control over a target response, under this framework, is a function of the reinforcement strengths of all the relevant contingencies (Figure 1). This framework is therefore different from the past analysis under behavioral approach that analyzed the strengths of the antecedent stimulus control as the synergistic contribution from the separate functions of MOs, i.e., $f(MO_1, MO_{2,} MO_{3\ldots})$, and/or reinforcers, i.e., $g(Reinforcer_1, Reinforcer_{2,} Reinfocer_{3\ldots})$. In contrast to the quadruple model proposed by Killeen and Jacobs (2017) that involved the state of the organism (O), discriminative stimulus (S^D), responses (R), and reinforcers (S^R), I argued that the organism's physiological/dispositional/motivational state (i.e., O) affected the value of MOs in the function of reinforcement strength rather than in the opposite way as stated by Killeen and Jacobs (2017, p. 26). The initial state of the organism (O) under this model, including the organism's physiological/dispositional/motivation state, affects the initial MOs related to the function of stimulus control over the target response. This integrated model accounted for the factor of "curiosity" under radical behaviorism without resorting to the mediating role of O, such that the motivating variable of "curiosity" affected the value of MOs in the function of stimulus control (Figure 1). The reconceptualization of the definition of MOs by attributing the influences of MOs on S^D to the MO definition allowed analyzing the reinforcement strengths of multiple contingencies without distinguishing the contribution of the MO and the reinforcer to the stimulus control under the same sub-contingency. The level of “curiosity” could be accounted for by the degree of the stimulus control under radical behaviorism, in which the target response was controlled by multiple correspondences involving MOs, S^D s, prosthetic reinforcers, and correction procedures.

Specifically, conditioning a previously non-preferred stimulus as a reinforcer under the corresponding contextual control establishes new stimulus control, such that the novel reinforcer functions as the selector in the science of human learning (Greer, 2020). S^D s simultaneously function as conditioned reinforcers and enjoy a certain level of reinforcement value corresponding to that of the primary reinforcers (Keller & Schoenfeld, 1950). A series of behavior analytic research has demonstrated that non-preferred visual stimuli, including academic stimuli (e.g., pictures, books, and math worksheets), could be established as conditioned reinforcers for students with and without disabilities (Buttigieg & Greer, 2021; Gentilini & Greer, 2020, 2021; Greer & Han, 2015; Maurilus, 2018; Lee, 2016; O’Rourke, 2006; Tsai & Greer, 2006). Following the establishment of academic stimuli as conditioned reinforcers, students could either learn at a faster rate or learn in new ways (Buttigieg & Greer, 2021; Gentilini & Greer, 2020, 2021; Maurilus, 2018; Lee, 2016; O’Rourke, 2006; Tsai & Greer, 2006). Since observing responses are operants (Holland, 1985), when the antecedent stimulus is a preferred visual stimulus for observing, the “see-say/do” correspondence to this preferred visual antecedent stimulus itself may establish a certain level of reinforcement for acquiring novel skills.

Additionally, the contingent consequences of prosthetic reinforcers following correct responses and the correction procedures following incorrect responses also set up MOs and in turn strengthen the stimulus control in skill acquisition. Multiple instruction procedures (e.g., discrete trial instruction and learn unit instruction) involving small units of three-term contingencies of S^D s, student responses, and contingent consequences were shown effective on improving academic achievement for students with and without developmental delays (Albers & Greer, 1991; Boudreau et al., 2015; Carroll et al., 2015, 2018; Ingham & Greer, 1992; Johnson et al., 2017; Karsten & Carr, 2009; Neu & Greer, 2019; Vladescu & Kodak, 2010). Several studies have compared the learning rates under conditions of (a) differential reinforcement without error corrections, in which the researchers moved on to the next trial without providing any consequences following students' incorrect responses, and (b) correction procedures along with differential reinforcement (Jessel et al., 2020; Kodak et al., 2016; Rapp et al., 2012; Worsdell et al. 2005). The results revealed that children demonstrated little improvement when error corrections were omitted and improvement when error-correction procedures and differential reinforcement were present. Thus, the correction procedure appears to be - at minimum - a necessary component (Ward-Horner & Sturmey, 2012) in skill acquisition. The correction procedure may sharpen the stimulus control as a result of negative reinforcement, such that additional prompted responses are required following the student's emission of an incorrect response before the trial is terminated (Cariveau et al., 2019; Rodgers & Iwata, 1991).

Moreover, when the S^D is a preferred visual stimulus, the modeling of the correct response in the correction procedure may also demonstrate a certain level of positive reinforcement for information acquisition. Fantino and Silberberg (2010) demonstrated that only "useful" information that functions as conditioned reinforcers can maintain the observing responses. The findings from neural science identified that dopamine neurons signaled both direct rewards and information, suggesting that acquisition of information also functioned as rewards in the learning process (Gruber et al., 2014). Thus, the modeling of the correct response for the preferred visual stimulus in the correction procedure might function as a positive reinforcer by allowing the immediate access to the “useful” information (Simonian & Brand, 2022).

Lastly, the set size of the antecedent stimuli may also affect the initial MO level and the strength of antecedent stimulus control in skill acquisition. Past research on skill acquisition varied widely regarding the selection of stimulus set size, ranging from one to 15 stimuli per session (Greer & Ross, 2008; Greer et al., 2020; Grow & LeBlanc, 2013; Haq et al., 2015; LaMarca & LaMarca, 2018; Leaf & McEachin, 1999; Lovaas, 2003; MacDonald & Langer, 2018; Maurice et al., 2001; Yaw et al., 2014). Kodak et al. (2020) manipulated the set size of the antecedent stimuli for three children (3- to 6-year-old males) and one adolescent (15-year-old male) diagnosed with autism spectrum disorder (ASD) and identified that although small and big stimulus set sizes were all effective, the set-size-six and -twelve conditions were more effective and efficient than set-size-three and -four in tacts acquisition for children with ASD. However, Vladescu et al. (2021) conducted a systematic replication for Kodak’s study with two adolescents with ASD and found contradicting results, in which the small stimulus set-size-three was more efficient than the large stimulus set-size-twelve on teaching tacts to students with ASD. Despite the opposite results of the two studies, the different effects of the stimulus set sizes on the rate of skill acquisition suggest the contribution of the antecedent stimulus set size to the strength of antecedent stimulus control in learning.

1.4 Purposes

A series of studies have demonstrated that the establishment of non-preferred academic stimuli as conditioned reinforcers were effective on improving students' academic performance (Gentilini & Greer, 2020, 2021; Greer et al., 2011; Longano & Greer, 2006; Nuzzolo-Gomez et al., 2002; Tsai & Greer, 2006). Since observing responses are operants (Holland, 1958), when the antecedent S^D is a preferred visual stimulus for observing, the see-say/do correspondence itself may establish a certain level of reinforcement. Although past research has investigated the effects of contingent consequences and preferred visual antecedent stimuli on the rate of learning respectively, no researchers have directly compared the stimulus control strengths of three-term contingencies in skill acquisition from the preferred visual antecedent stimuli and the contingent reinforcers. Thus, the purpose of Chapter 2 was to analyze the effects of the antecedent visual stimuli and the contingent consequences in skill acquisition for preschoolers with and without disabilities.

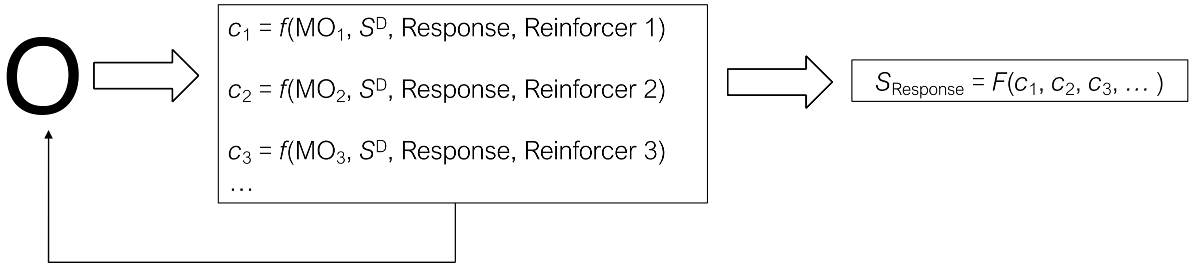
In Chapter 3, I controlled for the stimulus control from the antecedent stimuli and compared the strength of stimulus control between prosthetic reinforcers and correction procedures. Although a series of studies have investigated the synergistic effects of correction procedures and differential reinforcement in DTI for children with disabilities (Cariveau et al., 2019; Leaf et al., 2010; Scott et al., 2000; Smith et al., 2006; Vladescu & Kodak, 2010; Wordsdell et al., 2005), few researchers have conducted a component analysis of skill acquisition consequences to compare the effects of reinforcement and correction procedures. Such information will help elucidate whether a correction procedure is both necessary and sufficient for skill acquisition, which may in turn effectively facilitate students' learning in educational settings. The purpose of Chapter 3 was to analyze the component effects of skill acquisition consequences that involved contingent praise for correct responses (positive reinforcement operation) and corrections for incorrect responses.

In Chapter 4, I further manipulated the set size of antecedent stimuli and compared the strengths of antecedent stimulus control in skill acquisition across small, middle, and large stimulus set sizes. Since the two studies of Kodak et al. (2020) and Vladescu et al. (2021) (see previous section) demonstrated controversial results regarding the effects of stimulus set size on skill acquisition, the purpose of Chapter 4 was to conduct a systematic replication of Kodak et al.'s (2020) and Vladescu et al's (2021) research with further experimental control on the number of presentations per word per session with operant analysis (OA) acquisition criterion (Wong et al., 2021; Wong & Fienup, in press) that targeted the acquisition mastery of individual operant instead of set-based acquisition criteria as used by Kodak et al. (2020) and Vladescu et al. (2021).

To sum up, the purpose of this research was to analyze the effects of the aforementioned variables (e.g., the preference levels on observing the antecedent stimuli, the contingent consequences, and the antecedent stimulus set size) on skill acquisition under the integrated model proposed before (Figure 1). We also extended past findings by studying children with and without developmental delays. Such information will help identify the instruction procedures (e.g., the contingent consequences and the inclusion of preferred antecedent stimuli) that establish high motivating conditions toward academic subject, which may in turn effectively facilitate students' learning in various educational settings.

Figure 1

The hypothetical function of the strength of stimulus control among the synergistic strengths of reinforcement across multiple correspondences of MOs, S^Ds, the target response, and the corresponding reinforcers



Note. O represents the organism's physiological/dispositional/motivational state. c_i represents the function of reinforcement strengths (e.g., see-say/do correspondence, prosthetic reinforcer, correction procedure). S_{response} represents the function of stimulus control over a target response.

Chapter 2

See-Say Correspondences of Preferred Visual Antecedent Stimuli Function as Reinforcers Even When Non-Preferred Activities Are Consequences for Learning

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Abstract

We analyzed the strengths of stimulus control of the preferred visual antecedent targets and prosthetic reinforcers in skill acquisition. The preferred- (PA) and non-preferred-visual-antecedent-stimuli (NA) were paired with two contingent consequences. In the conditions paired with the consequence of praise-for-correct-responses (PC), researchers praised correct responses and implemented a correction procedure contingent on incorrect responses. In the conditions paired with the math-for-correct-responses (MC), the procedure was the same except that a correct response was followed by presenting a non-preferred activity of doing a math problem. We measured the acquisition rates and maintenance of responses of PA and NA across the two consequence conditions. The results showed that all participants acquired the PA faster regardless of the consequence conditions. The findings suggest that the see-say correspondence of the PA may function as a stronger reinforcer in skill acquisition than the contingent consequence of prosthetic reinforcer delivered by the instructor.

Keywords: preferred visual antecedent stimuli, prosthetic reinforcers, see-say correspondence, stimulus control, tact

See-Say Correspondences of Preferred Visual Stimuli Function as Reinforcers Even When Non-Preferred Activities Are Consequences for Learning

The selection processes involving variation, selection, and retention under evolutionary biology are functionally parallel to those under radical behaviorism, such that the former focuses on the group of organisms whereas the latter the individual organism (Donahoe, 2012). Nevertheless, stimulus control of three-term contingency is not perfect given its dependence on the related environmental context (Skinner, 1938, p. 241). Each reinforcer is under the contextual control of the corresponding motivating condition (Greer et al., 2017). The consequence of reinforcers under the corresponding contexts functions as the selectors in the science of human learning (Greer, 2020). Furthermore, the emission of a response might be the function of "multiple control" involving discriminative stimuli (SDs), reinforcers, and the associated motivating conditions (Greer et al., 2005; Edwards et al., 2019; Greer, 2020; Skinner, 1957, p. 227). SDs simultaneously function as conditioned reinforcers and enjoy a certain level of reinforcement value corresponding to that of the primary reinforcers (Keller & Schoenfeld, 1950). Thus, the strength of stimulus control over a target response in learning might be a function of multiple contingencies involving motivating operations (MOs), SDs, and the contingent consequences.

A variety of studies have focused on the manipulation of contingent consequences following correct responses and incorrect responses to facilitate learning for students with and without disabilities (Albers & Greer, 1991; Bahadourian et al., 2006; Carroll et al., 2015, 2018; Emurian, 2007; Kodak et al., 2016; McGhan & Lerman, 2013). The emission of a correct response by the student leads to the delivery of reinforcement (e.g., tangibles or tokens), whereas the emission of an incorrect response the correction procedures. The correction procedure usually involves prompts or models of the correct response immediately following the student's emission of an incorrect response and representation of the SD that allows independent response opportunities for the student (Albers & Greer, 1991; Cariveau et al., 2019). The results of these studies demonstrated that instructions (e.g., discrete trial instruction and learn unit instruction) with reinforcement following correct responses and correction procedure incorrect responses were effective on teaching new skills (e.g., tact, textual responding, and problem solving) to students with and without disabilities (Albers & Greer, 1991; Bahadourian et al., 2006; Carroll et al., 2015, 2018; Emurian, 2007; Jessel et al., 2020; Kodak et al., 2016; McGhan & Lerman, 2013; Rapp et al., 2012).

Additionally, a series of studies have demonstrated that the establishment of non-preferred academic stimuli as conditioned reinforcers improved students' academic performance with those stimuli (Gentilini & Greer, 2020, 2021; Greer et al., 2011; Longano & Greer, 2006; Nuzzolo-Gomez et al., 2002; Tsai & Greer, 2006). The non-preferred antecedent visual SDs, including academic stimuli (e.g., pictures, books, and math worksheets), could be established as conditioned reinforcers for students with and without disabilities (Du et al., 2015; Gentilini & Greer, 2020, 2021; Greer & Han, 2015; Singer-Dudek et al., 2011; Tsai & Greer, 2006). Following the establishment of academic stimuli as conditioned reinforcers, students could either learn at an enhanced rate or learn in new ways (Delgado et al., 2009; Gentilini & Greer, 2020, 2021). Since observing responses are operants (Holland, 1958), when the antecedent SD is a preferred visual stimulus for observing, the see-say/do correspondence itself may establish a certain level of reinforcement.

The findings on the effects of the establishment of derived relations such as Incidental Bi-directional Naming (Inc-BiN) on the students' rate of learning also suggested the reinforcing value from the see-say correspondence of preferred visual SDs. The degree of Incidental Bidirectional Naming in verbal behavior development demonstrates students' readiness for incidental language acquisition in the general education settings (Greer et al., 2017). The degree of stimulus control for Inc-BiN is associated with the emergence of untaught word-object relations without direct reinforcement for object naming (Greer et al., 2017). This differs from the aspect of Lowe et al.'s theory (Horne & Lowe, 1996; Lowe et al., 2002, 2005) that the existence of Inc-BiN facilitates other derived relations and refers to the aspect of their theory about children acquiring the names of things incidentally from exposures. This latter aspect has been extended to measuring how many exposures to the names of things needed by children to acquire the names of things from exposure alone. Several studies identified interventions (e.g., multiple exemplar instruction, intensive tact instruction, and repeated probe procedures) that could reliably induce the capability of Inc-BiN for children with disabilities (Fiorile & Greer, 2007; Greer et al., 2005; Hawkins et al., 2009; Hotchkiss & Fienup, 2020; Pistoljevic & Greer, 2006; Schmelzkopf et al., 2017). Recent research also identified repeated probe conditions that resulted in the onset of Inc-BiN and different levels of complexity (Kleinert et al., 2021).

Although past research has investigated the effects of contingent consequences and preferred visual antecedent stimuli on the rate of learning respectively, no researchers have directly compared the stimulus control strengths of three-term contingencies in skill acquisition from the visual antecedent stimuli and the contingent consequences. Such information will help identify the instruction procedures (e.g., the contingent consequences and the inclusion of preferred antecedent stimuli) that establish high motivating conditions toward academic subject, which may in turn effectively facilitate students' learning in various educational settings. The purpose of this study was to analyze the effects of the visual antecedent stimuli and contingent consequences in skill acquisition for preschoolers with and without disabilities. The preferred- (PA) and non-preferred-visual-antecedent-stimuli (NA) were paired with two contingent consequences. In the conditions paired with the consequence of praise-for-correct-responses (PC), researchers praised correct responses and implemented a correction procedure contingent on incorrect responses. In the conditions paired with the math-for-correct-responses (MC), the procedure was the same except that a correct response was followed by presenting a non-preferred activity of doing a math problem. We measured the acquisition rates and maintenance of responses in learning to tact the PA and NA across different consequence conditions. The goal was to distinguish the contribution to the stimulus control in skill acquisition from the see-say correspondence of the preferred visual stimuli and the prosthetic reinforcers delivered by instructors.

Method

Participants

The researchers selected six participants from an integrated classroom of a private preschool for children with and without developmental delays for this study. Five participants were educationally classified as preschoolers with developmental delays and one participant was typically developing. The classroom implemented the *Comprehensive Application of Behavior Analysis to Schooling* (CABAS$^{®}$) model of instruction (www.cabasschools.org; www.scienceofteaching.org). The participants' repertoires were assessed using the Early Learner

Curriculum and Achievement Record (ELCAR): A CABAS® Developmental Inventory (Greer, et al., 2020). All participants were able to follow multiple step vocal directions, make requests, and vocally respond to others. All participants had mastered pre-requisite repertoires such as imitating gross motor actions, orienting to and observing two dimensional stimuli, and echoing with point-to-point accuracy. Teachers' praise functioned as conditioned reinforcers for all participants - evidenced in the ELCAR assessment for listener and speaker responses, in which there were no differences between the percentage and rate of correct responses emitted by the participants in a probe session with the use of tangibles or tokens and praise. Participants Andrew, Jack, Adam, Kevin, and Amy had counting and matching number and quantity 1-10 in repertoire. Tom had counting and matching number and quantity 1-6 in repertoire. According to the ELCAR assessment, the manipulation of math functioned as non-preferred activity for all participants.

Andrew, Tom, Adam, and Kevin were 4-year-old males with developmental delays. Jack was a typically developing 3-year-old male. Amy was a 4-year-old female with developmental delays. Specific to this study, all participants had instructional history for learning tacts through learn unit (LU) instruction that included positive reinforcement for correct responses and correction procedures for incorrect responses. Detailed information regarding the participants' verbal behavior development is outlined in Table 1.

Setting and Materials

The experiment occurred in the participants' classroom. The classroom consisted of 9 students, including one typically developing student and eight students with developmental delays, one teacher and two teaching assistants. The teacher and/or teaching assistants delivered instruction to non-participant students in 1:1 or small group settings while the researchers conducted the study. The researchers measured all responses of the students (for this experiment and during daily instruction) with frequent interobserver agreement checks and rating of teacher accuracy of implementing instruction (Teacher Performance Rate and Accuracy, TPRA, Ingham & Greer, 1992).

The classroom contained a play area, three U-shaped small group stations, a small rectangular activity table and a large rectangular communal table. The researcher sat next to the participant at the communal table during the baseline, acquisition, and the probe sessions for maintenance of skills. The researcher used Microsoft PowerPoint to present the two-dimensional stimuli during the pre- and post-experimental probes and during acquisition. A laptop, math worksheets of A4 size, data collection sheets, a timer, and pens with black ink were used in the procedure. The matching problems on the math worksheets were according to the participants' respective repertoires. The sets of educational stimuli were selected based on the ELCAR goals. The stimuli used in the learning process and probe sessions for each participant are listed in Table 2. The sample math worksheet used in the experiment is listed in Figure 1.

Measurement

We measured four dependent variables in learning to tact novel educational stimuli for each participant. The primary dependent variable was the number of correct responses emitted by the participant in each instructional session. A correct response was defined as the participant tacting the visual stimulus accurately within 5 s following the researcher's presentation of the picture on the laptop. An incorrect response was defined as the participant emission of incorrect tacts or not responding within 5 s of the delivery of the antecedent.

The second dependent variable was the number of instructional trials required by the participant to meet the criterion for the stimulus sets of PA and NA across the two consequence conditions. We also measured the rate of responding in each instructional session. Since the duration for delivering a vocal praise was much shorter than completing a math problem, the durations of the consequences contingent on correct responses were significantly different in the two consequence conditions. Considering that both the consequences of PC and MC shared the same correction procedure following an incorrect response, we measured the number of incorrect responses per min in each instructional session until mastery. The rate of incorrect responses was calculated by dividing the duration of a session in minutes by the total number of incorrect responses per session. The duration of a session was measured as the time elapsed from the presentation of the first visual stimulus until the end of the consequence of the last learning opportunity (e.g., the delivery of praise/math problem following a correct response or correction following an incorrect response). Lastly, maintenance probes were conducted to measure the number of correct tacts during bi-weekly assessments for up to 8 weeks following the completion of the teaching phase. During maintenance, we recorded correct and incorrect responses in the same manner as during acquisition.

Independent Variable

We compared the skill acquisition rates of preferred and non-preferred visual stimuli across the two consequence conditions. In the conditions paired with the consequence of PC, the researcher praised independent correct responses (e.g., “you are right! It is spinach!”) and implemented a correction procedure contingent on incorrect responses. The correction procedure involved one response opportunity to echo the correct response modeled by the researcher followed by two independent response opportunities for correct responses. In the conditions paired with the consequence of MC, the procedure was the same as those paired with the PC except for the consequence following a correct response, in which the researcher delivered the non-preferred activity of doing a math problem (i.e., matching the quantity of shapes with the corresponding number) that was in the participants' repertoire. The researcher took away the worksheet and presented the next tact stimulus after the participant completed the problem. We manipulated the independent variables with preferred and non-preferred educational stimuli.

Experimental Design

We used an adapted alternating treatment design (Sindelar, 1985) in this study. We paired the participants into three dyads randomly and counterbalanced the assignment of the sets of the preferred and non-preferred visual stimuli to the two consequence conditions across the dyads. That is, three participants learned to tact the PA in the PC condition and the NA in the MC, whereas the other three participants (their dyad partners) learned the PA in the MC condition and the NA in the PC. Additionally, the researchers controlled the difficulty levels of the educational stimulus sets by limiting the number of syllables contained in each antecedent (Cariveau et al., 2021). The researchers selected four novel two-syllable educational stimuli from each of the two categories, electronic devices and vegetables. None of the stimuli in each set shared the same first syllable. During the instruction, the researchers counterbalanced the daily order of instruction conditions within each dyad and the targets across the three dyads to decrease the possibilities of sequence and carry-over effects through this procedure. All instructional sessions were conducted before lunch and the participant would participate in a different activity (e.g., free play, coloring, and writing letters) for at least 10 min between the two instructional sessions.

One instructional session for each set of stimuli was conducted for all participants per day.

Procedure and Data Collection

The procedure was presented in the following sequence: (a) probe the number of correct tact responses for the two sets of educational stimuli, (b) assess and identify the preferred set of visual stimuli, (c) start the instruction across the two consequence conditions until the participant's mastery of both sets of stimuli, and (d) probe the number of correct responses to the stimuli sets during bi-weekly maintenance assessments for up to eight weeks.

Pre-experimental probes to identify target stimuli

Prior to the experiment, we conducted probes to identify the two-dimensional stimuli not in the participant's repertoire for speaker responses for all participants. The researcher sat next to the participant at a rectangular table and presented the two-dimensional stimuli by PowerPoint on a laptop. Each session included four variations of the picture for each of the five targets (multiple exemplar instruction across visual variations, e.g., four different pictures of okra) for a total of 20 trials. Before each session the researcher told the participant "Now we are going to look at some pictures of vegetables/electronic devices". If the participant emitted the name of a picture accurately within 5 s following the researchers' presenting a stimulus on the laptop, we recorded it as a correct response. If the participant tact a target stimulus correctly with 100% accuracy, the researcher took out this stimulus and switched it to another stimulus of the same category that was not in the participants' repertoire. All probe trials were unconsequated.

Baseline

After identifying stimuli that were not in a participant's repertoire for both the sets of vegetable and electronic devices, the researchers conducted three probe sessions for the number of correct tacts emitted by all participants to each of the two sets of stimuli. The procedure was the same as that of pre-experimental probes. Responses were unconsequated during the baseline.

Preference Assessment

We assessed the participant's preference levels to the stimuli sets of vegetables and electronic devices three times immediately following each round of the baseline probes for the two stimuli sets. After presenting each of the two sets of stimuli to the participants, the researcher asked the participant to choose the preferred stimuli set (e.g., "which set do you want to learn first, vegetables or electronic devices?") and recorded the response. All participants demonstrated higher preference to the pictures of electronic devices (PA) over vegetables (NA) by selecting to learn the set of electronic devices first at least 2 out of 3 times. The detailed results of the assessment are listed in Table 3.

General Instructional Procedures for Reinforcer Assessment

The researcher sat next to the participant at a rectangular table and presented the two-dimensional stimuli on a laptop similar to the baseline and probe sessions. The researcher presented the visual stimuli, waited the participant's responses, and delivered contingent consequences based on the responses. The occurrences of correct and incorrect responses in each instructional session were recorded. Consistent with prior phases, each session consisted of the delivery of 20 discriminative stimuli (5 distinct stimuli, 4 opportunities for each, 4 versions of pictures). The criterion for acquisition in each condition was set at either 90% (18/20) accuracy or higher across two consecutive sessions. We continued the instruction until the participants met the criterion for both stimulus sets of PA and NA for Andrew, Tom, Jack, Adam, and Kevin, to ensure that they had the same amount of exposure to the stimuli before terminating instruction and moving to the maintenance assessments. Since the stimulus set of NA (i.e., vegetables) became aversive to Amy, we decided to stop the instruction for Amy after 20 instructional sessions for each of the two stimulus sets.

Praise-for-correct-responses paired with preferred-visual-antecedent-stimuli (PC-PA). The participants learned to tact the preferred visual stimuli (e.g., electronic devices) with the contingent consequence of PC in the PC-PA condition. We implemented the learn unit (LU) instruction in the experiment. LU instruction consists of three components: presentation of antecedent while the participant is attending, an opportunity for the participant to respond, and the delivery of reinforcement contingent on correct responses and correction on incorrect responses. If the participant tact the target picture accurately within 5 s following the presentation of the stimulus, the researcher vocally praised the participant’s response. Different variations of praise were used, all including the restatement of the correct tact in the praise (e.g., “you are right! It is a black radio!”). If the participant responded incorrectly or did not respond within 5 s following the antecedent, the researcher implemented a correction procedure, including: (a) the researcher’s modeling the correct response once, (b) requiring the participant to echo the modeled response, (c) removing and re-presenting the antecedent, and (d) requiring the participant to tact the target stimulus independently. The steps (c) and (d) were presented twice with the same antecedent in each correction procedure. The correct responses emitted by the participant during the correction procedure were unconsequated.

Praise-for-correct-responses paired with non-preferred-visual-antecedent-stimuli (PC-NA). PC-NA condition was identical to the PC-PA except that the non-preferred visual stimuli (e.g., vegetables) were paired with the consequence of PC.

Math-for-correct-responses paired with preferred-visual-antecedent-stimuli (MC-PA). MC-PA condition was the same as the PC-PA condition except that a correct response for the preferred visual stimulus was followed by the non-preferred activity of doing a math problem that was in the participant's repertoire. The researcher presented a math problem of matching the quantity of shapes with the corresponding number in a field of three numbers with the vocal direction "match". The participant was required to count the shapes and point to the matching number. The researcher took away the worksheet and presented the next tact stimulus after the participant completed the problem. The responses emitted by the participant to the math problem were unconsequated.

Math-for-correct-responses paired with non-preferred-visual-antecedent-stimuli (MC-NA). MC-NA condition was identical to the MC-PA except that the non-preferred visual stimuli were paired with the consequence of MC.

Maintenance Probes

The researcher conducted bi-weekly maintenance probes for up to 8 weeks following the instruction. The procedure was identical to that of the baseline probes. Maintenance probes of the MC-NA condition for Amy were omitted from this analysis because she failed to meet the criterion for the set of vegetables in this condition.

Interobserver Agreement and Treatment Fidelity

We collected interobserver agreement (IOA) using the trial-by-trial correspondence (Ingham & Greer, 1992), in which an observer simultaneously and independently collected data on students' responses. The researcher compared the scores for each individual trial and summarized the total number of agreed trials. IOA was calculated by dividing the total number of agreed trials by the total number of trials then multiplied by 100%. The independent observer collected data for 61.1% of the target identification, baseline, and preference assessment sessions, 56.3% of the instructional sessions, and 95.8% of maintenance sessions, all with an agreement of 100%.

We also measured treatment fidelity with TPRA form (Ingham & Greer, 1992), in which a supervisor observed the sessions and collected data on the researcher's adherence to the experiment procedure, including the accuracy of researchers' presenting antecedents, securing attending, and delivering contingent consequences as described in each condition (e.g., no reinforcement such as smiling or nodding following a correct response during the correction procedure). An instructional trial was recorded as incorrect if the researcher implemented at least one component incorrectly in the trial. Treatment fidelity was calculated by dividing the total number of correctly implemented components by the total number of components and multiplying by 100%. During the baseline for sets of educational stimuli, the supervisor collected data for 33.3% of the pre-experimental and preference assessment sessions, 15.9% of the instructional sessions, and 95.8% of the maintenance sessions, all with an agreement of 100%.

Results

Figure 1 displays the number of correct responses emitted by the three participants during baseline, acquisition, and maintenance when the preferred educational stimuli were paired with the PC (PC-PA) and non-preferred stimuli with the MC (MC-NA). Square data points represent those sessions when a participant's performance met the acquisition mastery criterion. For all participants, baseline responding was at a stable level of 0 out of 20 correct responses. During acquisition, Andrew (dyad 1) mastered the preferred stimuli set of electronic devices in the PC-

PA condition within 6 instructional sessions and required 4 additional sessions (66.7% more sessions) to master the non-preferred set of vegetables in the MC-NA condition (top panel, Figure 1). During maintenance, Andrew responded with 100% accuracy (20/20) across the PC-PA and MC-NA conditions at 8 weeks following the termination of instruction. Similarly, Jack (dyad 2) learned to tact the preferred stimuli set (i.e., electronic devices; 4 sessions) with 4 fewer sessions (50% fewer sessions) in the PC-PA condition than the non-preferred stimuli (i.e., vegetables; 8 sessions) in the MC-NA condition (middle panel, Figure 1). During maintenance, Jack responded with 100% accuracy (20/20) for the preferred and non-preferred targets learned across the PC-PA and MC-NA conditions 8 weeks after instruction. Amy (dyad 3) required 14 sessions to master the set of preferred stimuli (i.e., electronic devices) in the PC-PA condition (bottom panel, Figure 1). She failed to meet the criterion for the non-preferred stimuli set of vegetables in the MC-NA condition following 20 instructional sessions. Amy responded with 19/20 accuracy for the preferred stimuli in the PC-PA condition at 8 weeks after the instruction. Overall, all participants learned faster in the PC-PA condition than the in the MC-NA condition.

Figure 2 displays the number of correct responses emitted by the other three participants (the dyad partners of Andrew, Jack, and Amy) when the preferred educational stimuli were paired with the MC (MC-PA) and the non-preferred stimuli the PC (PC-NA). Baseline responding was also at a stable level of 0 out of 20 correct responses for all participants. During acquisition, Tom (dyad 1) required 2 fewer sessions (33.3% fewer sessions) to meet the criterion for the preferred stimuli set (4 sessions) in the MC-PA condition than for the non-preferred stimuli of vegetables in the PC-NA condition (6 sessions) (top panel, Figure 2). Tom had 100% accuracy (20/20) during maintenance across the two conditions for the preferred and non-preferred stimuli sets. Similarly, Adam (dyad 2) mastered the preferred stimuli set (i.e., electronic devices) in the MC-PA condition in 9 sessions and the non-preferred stimuli (i.e., vegetables) in the PC-NA condition in 11 sessions (22% more sessions than in the MC-PA condition) (middle panel, Figure 2). He responded with similar level of accuracy during maintenance across the two conditions at 8 weeks following the instruction: 20/20 for the non-preferred stimuli in the MC-PA condition and 19/20 for the preferred stimuli in the PC-NA condition. Kevin (dyad 3) required one fewer session (10% fewer) to master the preferred stimuli in the MC-PA condition than the non-preferred stimuli in the PC-NA condition (bottom panel, Figure 2). During maintenance, Kevin had a slightly higher accuracy level for targets learned under the PC-NA condition: 19/20 for the preferred stimuli in the MC-PA condition and 20/20 for the non-preferred stimuli in the PC-NA condition. Overall, all participants learned faster for the set of preferred visual stimuli (i.e., electronic devices) with the consequence of MC than for the non-preferred visual stimuli (i.e., vegetables) in the PC-NA condition.

To compare the results in Figures 1 and 2, all participants learned faster for the set of PA (i.e., electronic devices), regardless of the consequences of PC and MC. When the preferred educational stimuli were paired with the PC (PC-PA), the participants (Andrew, Jack, Amy, Figure 1) acquired the targets dramatically faster (30–50% faster) than in the MC-NA condition. Even when the non-preferred activity of doing a math problem was consequence for a correct response, the participants (Tom, Adam, Kevin, Figure 2) learned at an enhanced rate (10–33% faster) for the PA. During maintenance, all participants demonstrated the same or similarly high levels of accuracy (19/20 or 20/20) at 8 weeks following the instruction for the preferred and non-preferred stimuli sets across all conditions.

Table 4 shows the total number of trials until mastery during acquisition for all participants. All participants required at least an average of 64 fewer trials (29% fewer) to master the preferred educational stimuli (i.e., electronic devices in the PC-PA and MC-PA conditions) than the non-preferred stimuli (i.e., vegetables in the PC-NA and MC-NA conditions), regardless of the consequence conditions. When the PA was paired with the consequence of PC (PC-PA) and the NA with the MC (MC-NA), Andrew, Jack, and Amy required at least an average of 93 fewer trials (37% fewer) to master the preferred stimulus set than the non-preferred set. Even when the non-preferred math activity and correction procedures were consequences in learning, their dyad partners (Tom, Adam, Kevin) mastered the preferred educational stimuli with an average of 33 fewer trials (18% fewer) in the MC-PA condition, than the non-preferred stimuli in the PC-NA condition.

Figures 3 and 4 display the number of incorrect responses per min in each instructional session until mastery during the acquisition of the preferred and non-preferred educational stimuli for all participants. Regardless of the consequence conditions, the rates of incorrect responses dropped faster for the preferred educational stimuli (i.e., electronic devices in the PC-PA and MC-PA conditions) than the non-preferred stimuli (i.e., vegetables in the PC-NA and MC-NA conditions). When the preferred stimuli were paired with the consequence of MC (MC-PA), the participants (Tom, Adam, Kevin) consistently emitted incorrect responses at a lower rate for the preferred set of stimuli than for the non-preferred set throughout the instruction (Figure 4). For Andrew and Jack, the number of incorrect responses per min for the preferred stimuli in the PC-PA condition were slightly higher than the non-preferred stimuli in the MC-NA condition for the initial two sessions but dropped to an evidently lower level for the rest of the instruction (top and middle panels, Figure 3). Similarly, the rates of incorrect responses for Amy for the preferred visual stimuli in the PC-PA condition were at similar levels for the initial 5 sessions as the non-preferred stimuli in the MC-NA condition (bottom panel, Figure 3). The number of incorrect responses per min for the preferred stimuli decreased gradually and maintained lower than the non-preferred stimuli after 5 sessions. Overall, all participants emitted lower rates of incorrect responses for the preferred visual stimuli (i.e., PC-PA and MC-PA) than the non-preferred stimuli (i.e., PC-NA and MC-NA), regardless of the consequence conditions.

Discussion

The results demonstrated that all participants acquired novel tacts faster for the stimulus set of preferred visual targets (i.e., electronic devices) than the non-preferred visual targets (i.e., vegetables), regardless of the consequence conditions. Additionally, all participants maintained at over 90% accuracy (19/20 and 20/20) for both the preferred and non-preferred stimulus sets regardless of the consequence conditions at 8 weeks following the instruction. These findings indicated that the preferred visual antecedent stimuli enjoyed a higher contribution to the stimulus control in skill acquisition than the prosthetic reinforcers.

This study was the first study that analyzed the effects of the preferred visual antecedent targets and the contingent consequences in LU instruction. Past research focusing on the effects of contingent consequences on skill acquisition demonstrated that the package of differential reinforcement and multiple correction procedures (e.g., demonstration, active student response, and multiple response repetition) were effective in teaching new skills (e.g., tact and textual responding) to children with and without disabilities (Emurian, 2007; Jessel et al., 2020; Kodak et al., 2016; Rapp et al., 2012; Worsdell et al. 2005). Previous studies also demonstrated that the non-preferred visual antecedent stimuli, including academic stimuli (e.g., pictures, books, and math worksheets), could be established as conditioned reinforcers for students with and without disabilities (Gentilini & Greer, 2020, 2021; Greer & Han, 2015; Singer-Dudek et al., 2011, Tsai & Greer, 2006). After the establishment of academic stimuli as conditioned reinforcers, students could either learn at an enhanced rate or learn in new ways (Delgado et al., 2009; Gentilini & Greer, 2020, 2021). When the temporal context regarding the access to the primary reinforcer is controlled, choice matches the rates of observing stimuli produced (Fantino, 2008). Thus, the choice outcomes in the preference assessment matches the preferences of the observing responses to the two sets of educational stimuli. The higher preference to observing the pictures of electronic devices than vegetables were affected by the participant's respective reinforcement history. Since observing responses are operants (Holland, 1985), the results of this study extended past findings and suggested that the see-say correspondence of the preferred visual stimulus may establish instant reinforcement that facilitates the acquisition of novel skills. Furthermore, the strength of the instant reinforcement from the see-say correspondence of preferred visual stimuli may be higher than the contingent consequence of prosthetic reinforcers in skill acquisition.

The results regarding the stimulus control strength of the preferred visual stimuli in learning also extended Fantino and Silberberg's (2010) finding that only "useful" or positive information could function as conditioned reinforcers and maintain the observing responses. According to Staats (1975), every unconditioned stimulus that elicits a response also functions as a reinforcer for the related instrumental responses and both functions (i.e., SD and reinforcer) of this stimulus will transfer to the newly conditioned stimulus for the same instrumental responses.

Similarly, when the antecedent stimulus is a preferred visual stimulus that elicits the observing response, this preferred visual stimulus may also function as a reinforcer for the related and post-cedent instrumental response (e.g., tact). The see-say correspondence of the preferred visual stimuli (e.g., electronic devices) may provide “positive” information to maintain the observing responses in skill acquisition. The results in this study were consistent with the findings from neuroscience that the brain areas related to rewards and learning (e.g., the frontopolar cortex and intraparietal sulcus) were significantly more active during exploration (e.g., acquiring information on novel images) (Daw et al., 2006; Kidd & Hayden, 2015; Heilbronner & Platt, 2013; Pearson et al., 2011; Wittmann et al., 2008).

Additionally, the outcomes of current study extended previous findings on the effects of the establishment of derived relations such as Incidental Bi-directional Naming (Inc-BiN) on the students’ rate of learning. A variety of studies have identified that several interventions (e.g., multiple exemplar instruction, intensive tac instruction, and repeated probe procedures) involving repeated and prolonged exposures to the visual stimuli could reliably induce the capability of Inc-BiN and in turn facilitate the learning rates for children with disabilities (Fiorile & Greer, 2007; Greer et al., 2005; Hawkins et al., 2009; Pistoljevic & Greer, 2006; Schmelzkopf et al., 2017). This study distinguished the contribution from the preferred visual antecedent stimuli to the stimulus control in skill acquisition. The high strength of the instant reinforcement from the see-say/do correspondence of preferred visual antecedent stimuli might be the reason why students learned faster after the establishment of Inc-BiN. The findings of current research also provided rationale regarding the effects of the interspersal of known items in skill acquisition (e.g., sight words and match-to-sample), such that the stimulus control of the preferred known visual stimuli might transfer to the novel non-preferred visual stimuli (Bottini et al., 2018; Browder & Shear, 1996; Knight et al., 2003; Benavides et al., 2009).

This experimentation is limited in three aspects. First, we did not replicate the results with novel stimuli sets. Since all participants preferred the stimuli sets of electronic devices over vegetables in the pre-experimental assessment, they might get more exposures to the electronic devices than vegetables outside school. Although we controlled the chance of exposure outside the school settings by including outdated electronic devices (e.g., pager), it would help verify the higher contribution from observing the preferred visual stimuli to the stimulus control in skill acquisition than the prosthetic reinforcers delivered by instructors with varied sets of preferred and non-preferred stimuli across more participants. Secondly, we continued to rotate between the two stimulus sets until the participants met the acquisition criterion in both conditions. Although this arrangement ensured that the participants had the same amount of exposure to the stimuli in the instruction, the extra trials to the stimuli after reaching the mastery criterion might lead to higher maintenance levels for the first mastered condition (i.e., the preferred set of stimuli). Since we continued to use the two sets of stimuli during the performance tasks for other instructions for all participants after the termination of the instruction, the high levels of maintenance across the two consequence conditions might be a result of the prolonged exposure to the stimuli sets. We may further rule out this possibility by terminating the instruction and entering the maintenance probes for a condition immediately following the mastery and controlled the contacts with the stimuli until the end of the experiment. Lastly, the researcher incorrectly included the stimulus “walkie talkie” that had a total of four syllables in the set of electronic devices for all participants. This may increase the learning difficulty for the set of electronic devices. However, all participants mastered the preferred set of visual stimuli (i.e., electronic devices) faster, regardless of the consequences. Nevertheless, it would help verify the instant reinforcement from the see-say correspondence of the preferred visual antecedent stimuli by controlling the number of syllables of all targets.

The outcomes of current study suggest several areas for future research. Since the consequence of MC, which involved the delivery of correction procedures contingent on incorrect responses but no prosthetic reinforcers following the correct responses, was effective on learning tacts for all participants in the MC-PA condition and for five out of six participants in the MC-NA condition, future research may further investigate the role of correction procedures in skill acquisition. Additionally, all participants in the study were high functioning with regard to language development (e.g., follow multiple step instructions; independently make requests using full sentences) and self-management skills (e.g., sit at the table appropriately for 5 min). Thus, the effectiveness of the MC-PA and MC-NA conditions without the delivery of prosthetic reinforcers might be influenced by the participants' high levels of compliance and robust verbal repertoires. The generality of the results to children with lower levels of compliance, less robust verbal repertoires, and different instructional histories needed further verification. Future research may also replicate the procedure with different preferred and non-preferred stimuli sets and multiple instruction programs requiring different responding topographies. Lastly, future research may investigate and compare the effects of preferred visual stimuli and contingent consequence conditions using other prosthetic reinforcers (e.g., tokens and edibles). Despite the need of future research to further clarify aforementioned concerns, the findings in this study identified the contribution from the preferred visual stimuli to the stimulus control in skill acquisition, which provides valuable information for instructors regarding the arrangement of instruction procedures (e.g., conditioning non-preferred visual stimuli as reinforcers and inducing the capability of BiN) and may in turn effectively improve the students' academic achievement in varied educational settings.

Table 1

Detailed information of relevant verbal behavior cusps for all participants

Cusps and Capabilities	Description	Dyad 1		Dyad 2		Dyad 3	
		Andrew	Tom	Jack	Adam	Kevin	Amy
Incidental Bi-directional Naming (Inc-BiN)	Inc-BiN allows the learning of word-object relations incidentally without the need of direct instruction. BiN has three levels: Pre-UniN, Uni-directional Naming (UniN), Bi-directional Naming (BiN).	UniN (listener responses: 100% accuracy; speaker responses: 0% accuracy)	Pre-UniN (listener responses: 50% accuracy; speaker responses: 35% accurary)	Pre-UniN (listener responses: 50% accuracy; speaker responses: 5% accuracy)	UniN (listener responses: 80% accuracy; speaker responses: 25% accuracy)	Pre-UniN (listener responses: 60% accuracy; speaker responses: 0% accuracy)	Pre-UniN (listener responses: 60% accuracy; speaker responses: 5% accuracy)
Generalized Imitation (GI)	GI enables the "see-do" correspondence without the need of direct instruction.	100% accuarcy for two-step imitations	90% accuarcy for two-step imitations	100% accuarcy for two-step imitations	100% accuarcy for two-step imitations	100% accuarcy for two-step imitations	100% accuarcy for two-step imitations
Auditory Matching (AM)	AM allows auditory matching to sample (MTS) for speech.	100% accuracy	90% accuracy	100% accuracy	100% accuracy	87% accuracy	70% accuracy
Listener Literacy (Phonemic stimulus control)	Listener literacy enables learning from spoken instructions with or without the presence of visual distractors.	100% accuracy for two-step vocal directions	80% accuracy for two-step vocal directions	100% accuracy for two-step vocal directions	90% accuracy for two-step vocal directions	80% accuracy for two-step vocal directions	100% accuracy for two-step vocal directions
Independent Mand (IM)	IM allows mediating the environment under the condition of deprivation with verbal operants.	100% accuracy using full sentences	90% accuracy using full sentences	100% accuracy using full sentences	100% accuracy using full sentences	80% accuracy using full sentences	100% accuracy using full sentences
Independent Tact (IT)	IT allows recruiting adult social attention under non-verbal stimulus control with verbal operants.	100% accuracy using full sentences	80% accuracy using full sentences	100% accuracy using full sentences	100% accuracy using full sentences	100% accuracy using full sentences	100% accuracy using full sentences
Intraverbal	Intraverbal enables verbally responding to questions in academic and social interactions.	90% accuracy using full sentences	80% accuracy using full sentences	100% accuracy using full sentences	80% accuracy using full sentences	90% accuracy using full sentences	100% accuracy using full sentences
Autoclitics	Autoclitics enables one to describe, qualify, quantify, manipulate, and relate to tacts and mands without direct instruction.	100% accuracy using 1 autoclitic	80% accuracy using 1 autoclitic	100% accuracy using 1 autoclitic	100% accuracy using 1 autoclitic	80% accuracy using 1 autoclitic	100% accuracy using 1 autoclitic

Note. Verbal behavior development includes four metamorphosis stages: pre-verbal, listener, speaker, and joining of listener and speaker (Greer et al., 2017). The level of verbal behavior for all participants is listener and speaker.

Table 2

List of 2D stimuli used in the baseline, acquisition, and maintenance probes

Stimuli Sets	Andrew	Tom	Jack	Adam	Kevin	Amy
Vegetables	Spinach, Endive, Tofu, Scallion, Okra	Spinach, Radish, Tofu, Scallion, Okra	Spinach, Radish, Tofu, Scallion, Okra	Endive, Radish, Tofu, Scallion, Okra	Spinach, Endive, Tofu, Scallion, Okra	Spinach, Radish, Tofu, Scallion, Okra
Electronic Devices	Pager, Walkie Talkie, Headphone, Scanner, Radio	Pager, Walkie Talkie, Headphone, Scanner, Radio	Pager, Walkie Talkie, Headphone, Scanner, Radio	Pager, Walkie Talkie, Headphone, Scanner, Radio	Pager, Walkie Talkie, Headphone, Scanner, Radio	Pager, Walkie Talkie, Headphone, Scanner, Radio

Table 3

The frequencies that the participants chose to learn the stimuli set of vegetables and electronic devices, respectively, in the assessment for the preferred visual stimuli

Participants	Frequency to Choose Vegetables	Frequency to Choose Electronic Devices
Andrew	0	3
Tom	0	3
Jack	0	3
Adam	1	2
Kevin	1	2
Amy	0	3

Table 4

The total number of trials required until mastery for the preferred and non-preferred stimuli sets in the PC-PA, PC-NA, MC-PA, and MC-NA conditions

Participants	Total Trials Required until Mastery	
	Non-Preferred Visual Stimuli - Vegetables	Preferred Visual Stimuli - Electronic Devices
Andrew	200	120*
Tom	120	80*
Jack	160	80*
Adam	220	180*
Amy	> 400	280*
Kevin	200	180*
Mean	217	153*

Note. Grey numbers represent the conditions paired with the consequence of MC and black numbers the consequence of PC.

Figure 1

The math worksheets used in the instructional sessions. Various math problems as shown were used in the instructional sessions

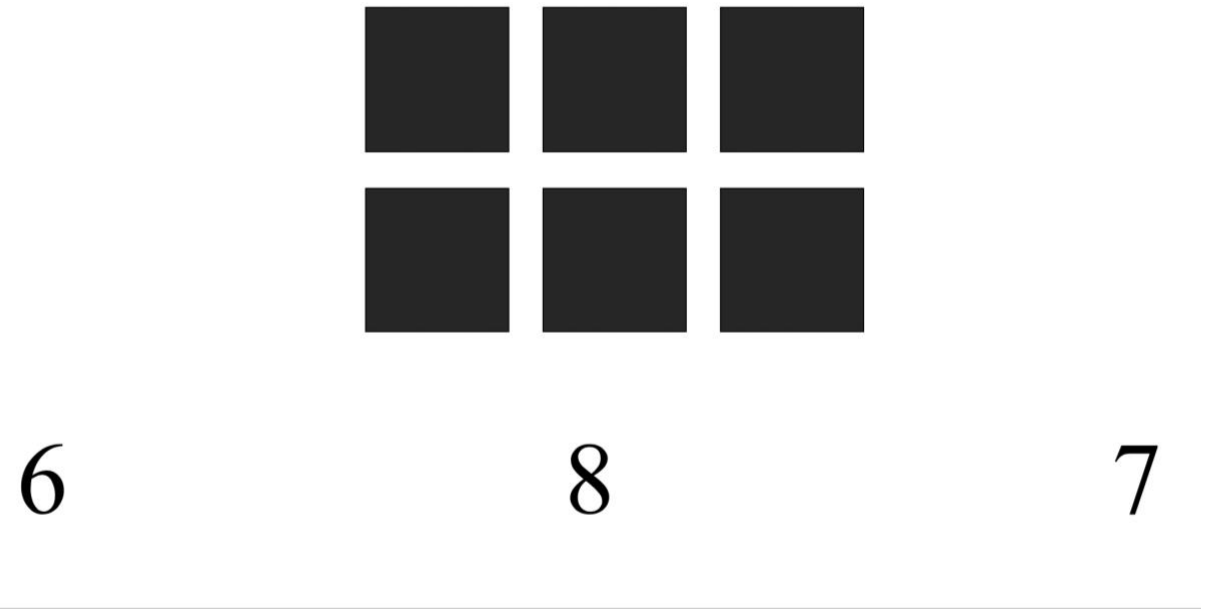
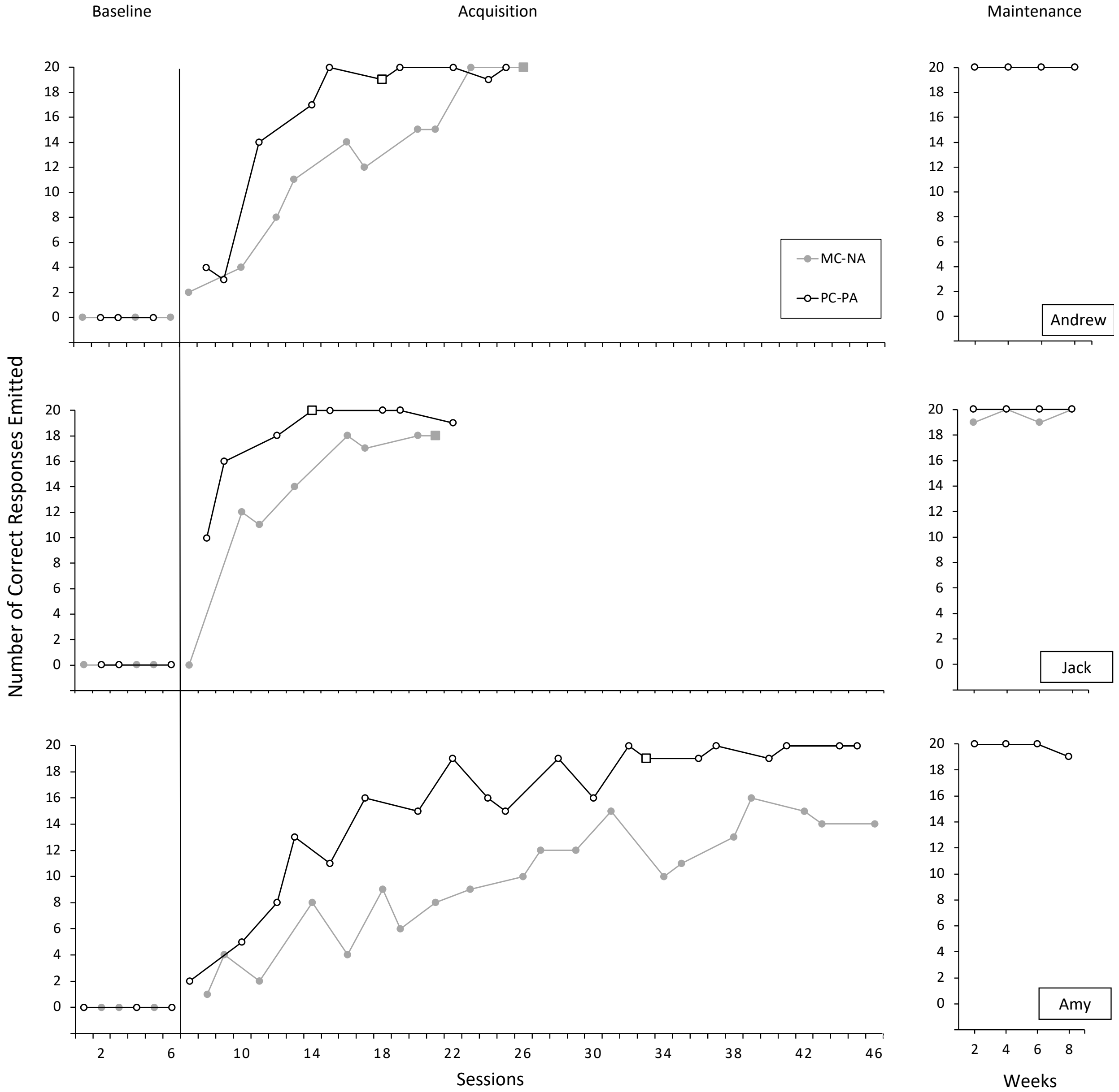


Figure 2

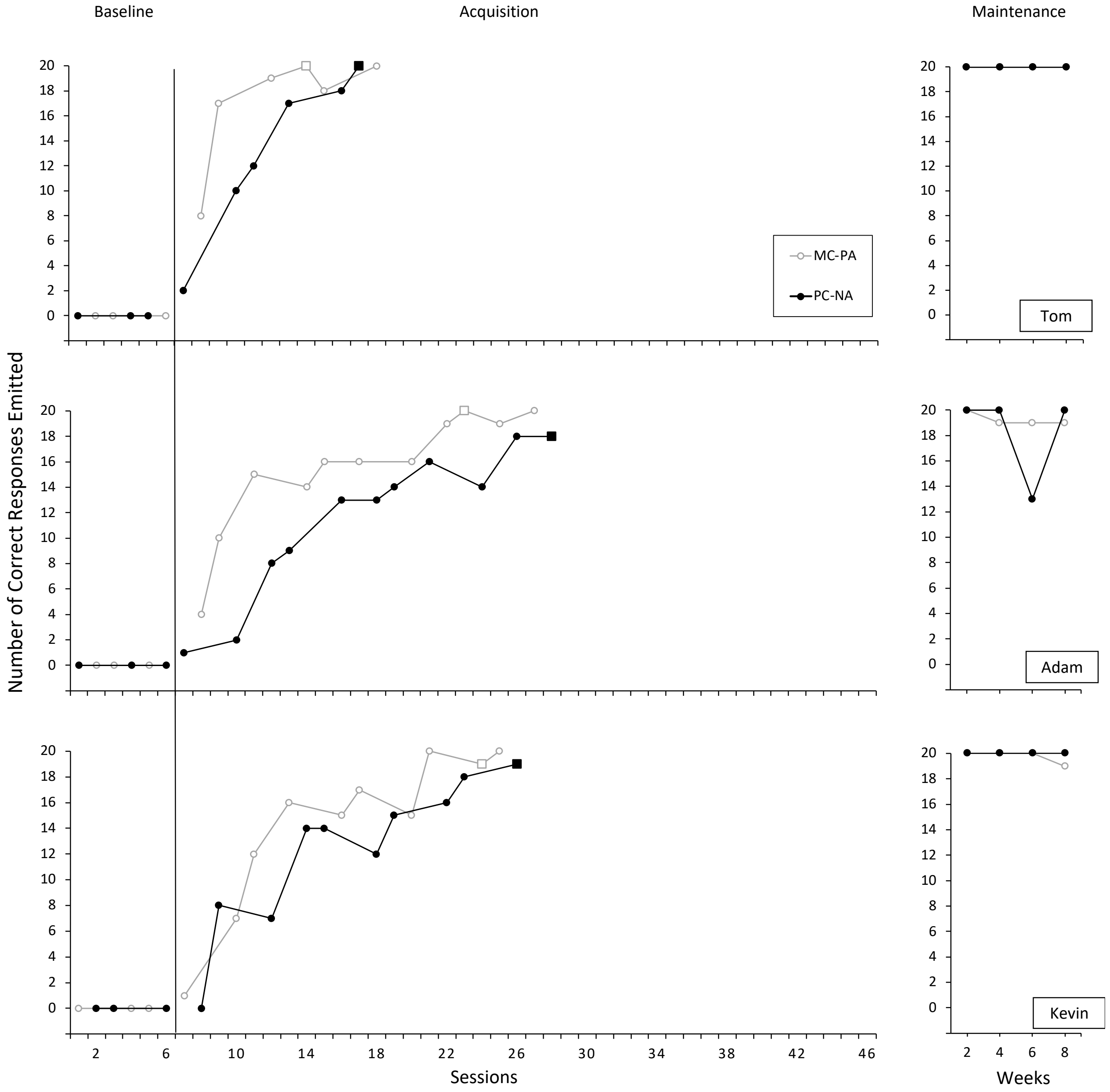
Baseline, acquisition, and maintenance data for Andrew (Dyad 1), Jack (Dyad 2), and Amy (Dyad 3) in learning preferred and non-preferred educational stimuli



Note. Square data points represent sessions where a participant's performance met the mastery criterion.

Figure 3

Baseline, acquisition, and maintenance data for Tom (Dyad 1), Adam (Dyad 2), and Kevin (Dyad 3) in learning preferred and non-preferred educational stimuli



Note. Square data points represent sessions where a participant's performance met the mastery criterion.

Figure 4

Rate of incorrect responses emitted by the participants until mastery for Andrew (Dyad 1), Jack (Dyad 2), and Amy (Dyad 3) in learning preferred and non-preferred educational stimuli

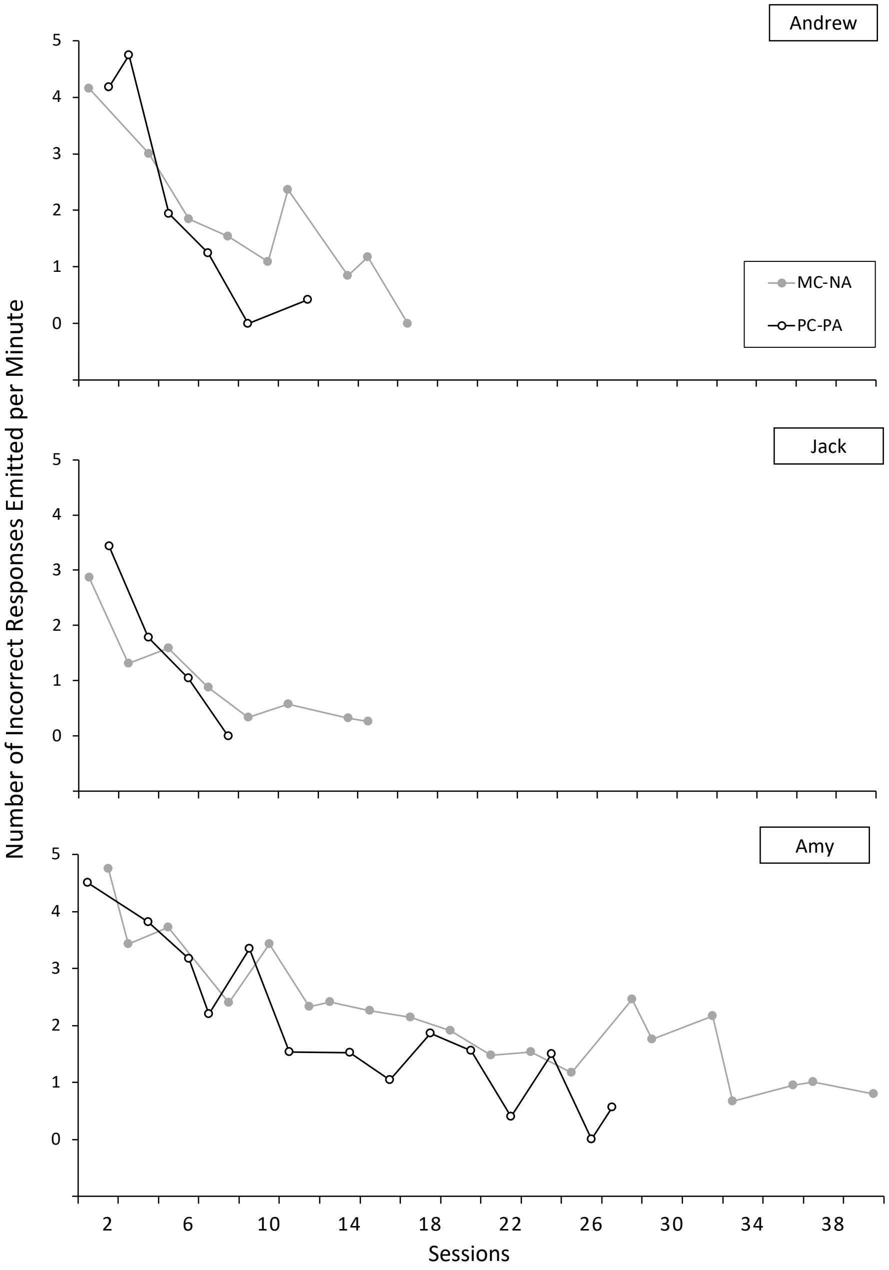
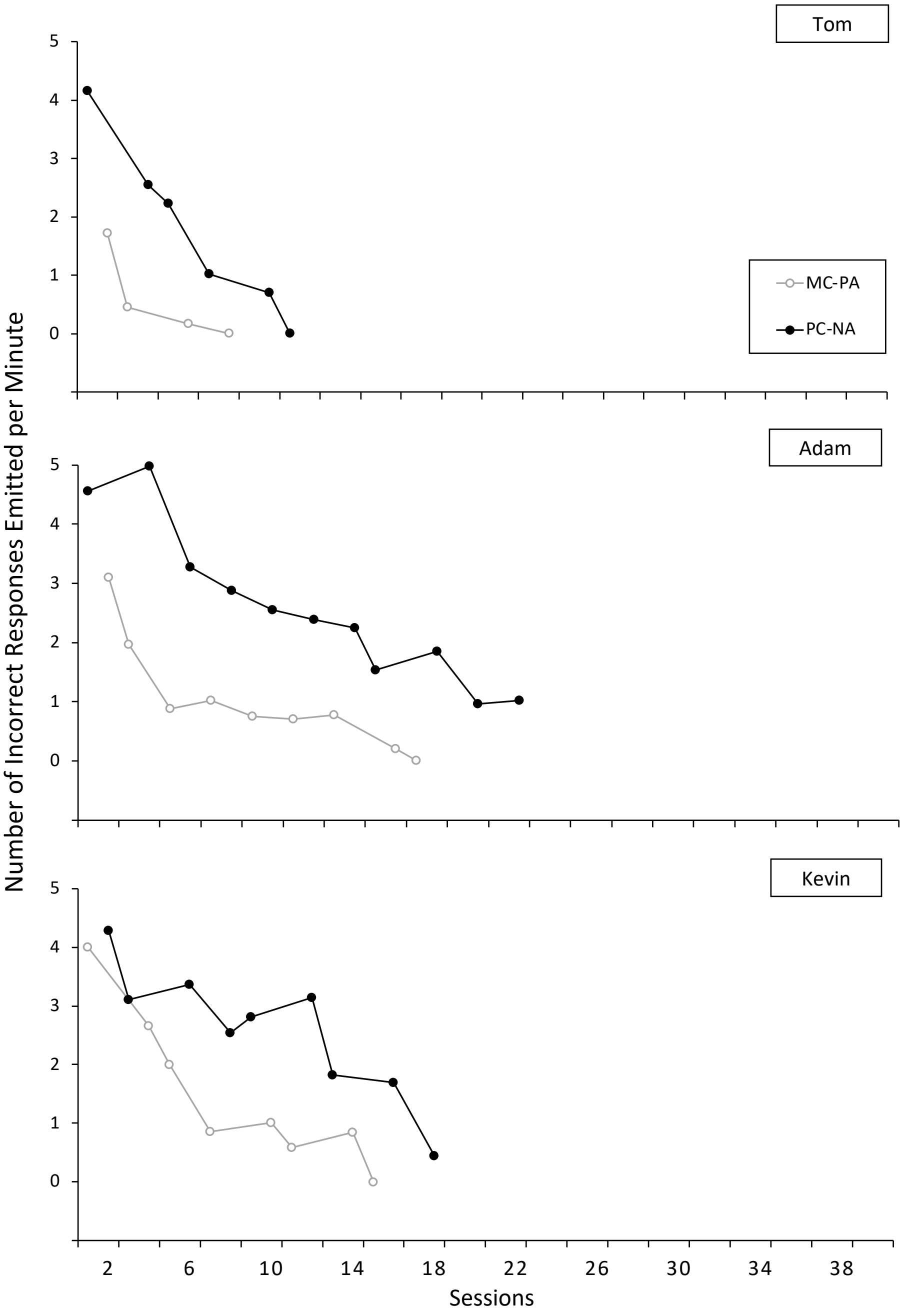


Figure 5

Rate of incorrect responses emitted by the participants until mastery for Tom (Dyad 1), Adam (Dyad 2), and Amy (Dyad 3) in learning preferred and non-preferred educational stimuli



Chapter 3

A Component Analysis of Skill Acquisition Consequences: Effects of Praise and Correction on Listener Responses

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Abstract

We conducted a component analysis of skill acquisition consequences for correct and incorrect responses. In the learn unit (LU) condition, researchers praised correct responses and implemented a correction procedure contingent on incorrect responses. In the praise-only-for-correct-responses (PC) condition, researchers delivered contingent praise for correct responses and ignored incorrect responses. In the correction-only-for-incorrect-responses (CI) condition, researchers ignored correct responses and implemented the correction procedure contingent on incorrect responses. We manipulated this independent variable across educational and abstract stimuli and measured acquisition rate, duration, and maintenance of responses. The results showed that the LU and the CI conditions were both effective on teaching listener responses and were more effective than the PC procedure. Furthermore, the LU instruction was not necessarily more efficient than the CI condition on acquisition of listener responses. The results suggested that the correction procedure was probably necessary and sufficient for skill acquisition and maintenance.

Keywords: correction procedure, discrete trial instruction, learn unit instruction, praise, skill acquisition consequence

A Component Analysis of Skill Acquisition Consequences with Listener Responses

Discrete trial instruction (DTI) has been used for decades to improve academic achievement for children with autism and developmental delays (Koegel et al., 1977; Lovaas, 2003; Smith, 2001). DTI involves small units of three-term contingencies, including the discriminative stimuli, prompts (as necessary), student responses, contingent consequences, and intertrial intervals (Smith, 2001). Prosthetic reinforcers and correction procedures are widely used as consequences in DTI. Contingent positive reinforcement for correct responses and correction procedures contingent on incorrect responses may influence the efficiency of skill acquisition for children with autism and developmental delays in DTI (Cariveau et al., 2019; Leaf et al., 2010; Scott et al., 2000; Smith et al., 2006; Vladescu & Kodak, 2010; Wordsdell et al., 2005).

A variety of studies have focused on the manipulation of differential reinforcement following correct responses to facilitate skill acquisition for children with disabilities (Boudreau et al., 2015; Johnson et al., 2017; Karsten & Carr, 2009; Vladescu & Kodak, 2010). Differential reinforcement refers to the delivery of higher-quality, higher-magnitude, shorter delay, or denser schedules of reinforcement following independent correct responses and lower-quality, smaller-magnitude, longer delay, or leaner schedules of reinforcement following prompted correct responses in an error-correction procedure (Jessel et al., 2020; Vladescu & Kodak, 2010). The results of these studies demonstrated that although differential reinforcement tended to be more efficient, nondifferential and differential reinforcement were often both effective on teaching new skills (e.g., tact and textual responding) to children with disabilities (Campanaro et al., 2020; Johnson et al.; 2017; Karsten & Carr, 2009).

The implementation of differential reinforcement is commonly used simultaneously with error correction procedures (Carroll et al., 2015, 2018; Joachim & Carroll, 2018; Kodak et al., 2016; McGhan & Lerman, 2013). A typical correction procedure consists of four components, including (a) prompts or models of the correct response immediately following the student's emission of an incorrect response, (b) the student's response, (c) differential reinforcement of correct responses (e.g., the delivery of less preferred items in correction procedures), and (d) an additional work requirement following errors, which may function as a punishment contingency (e.g., re-present the discriminative stimulus and require the emission of the target responses multiple times; Worsdell et al., 2005). Several studies have compared the learning rates under conditions of differential reinforcement and without correction procedures (Jessel et al., 2020; Kodak et al., 2016; Rapp et al., 2012; Worsdell et al. 2005). The results revealed that children demonstrated little improvement when correction procedures were omitted and improvement when correction procedures and differential reinforcement were present. Thus, the correction procedure appears to be - at minimum - a necessary component (Ward-Horner & Sturmey, 2012) of skill acquisition programming.

Although a number of studies have investigated the synergistic effects of correction procedures and differential reinforcement in DTI for children with disabilities, few researchers have conducted a component analysis of skill acquisition consequences to compare the effects of reinforcement and correction procedures. Neu and Greer (2019) identified the critical role of correction procedure in observational learning, such that typically developing fifth graders learned novel math skills by observation faster when they observed their peers only receiving contingent corrections to incorrect responses as compared to only receiving positive reinforcement following correct responses. Direct investigations on the component effects of correction procedure in skill acquisition will further elucidate whether a correction procedure is both necessary and sufficient for skill acquisition, which may in turn effectively facilitate students' learning in educational settings. However, the ubiquitous application of differential reinforcement in DTI, which usually involves the delivery of less preferred items following prompted correct responses in the correction procedure, makes it difficult to isolate the effects of correction procedures from positive reinforcement in skill acquisition (Kodak et al., 2016; Rapp et al., 2012; Worsdell et al. 2005).

Learn unit (LU) instruction[1], a type of DTI, includes both positive reinforcement for correct responses and correction procedures for incorrect responses. Essentially, LU instruction moves the traditional antecedent strategy of prompts to the consequence portion of instruction, delivered during error correction, and includes no reinforcement of prompted responses. Such exclusion of reinforcement from the correction procedure allows direct comparison of the effects of different consequences in skill acquisition, or a component analysis of skill acquisition consequences for correct and incorrect responding (Albers & Greer, 1991; Greer, 2002; Greer & McDonough, 1999).

The purpose of this study was to analyze the component effects of skill acquisition consequences that involved contingent praise for correct responses (positive reinforcement operation) and corrections for incorrect responses. Since related research in DTI focused more on

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[1] LU instruction interlocks three-term contingencies for both student and teacher, in which a student's observing responses are discriminative stimuli for a teacher to provide antecedents and a student's correct/incorrect responses are discriminative stimuli for a teacher to provide differential consequences, and the student's ultimate independent responses functions as the reinforcer for a teacher's behavior (Albers & Greer, 1991). The three-term contingency of DTI refers to the student's operant in LU, including the presentation of the antecedent, the student's response, and the delivery of positive reinforcement following a correct response and correction procedure an incorrect response.

speaker responses and students with disabilities, we extended past findings to the acquisition of listener responses (i.e., auditory-visual conditional discriminations, AVCDs) for preschoolers with and without disabilities. In the learn unit (LU) condition, researchers praised correct responses and implemented a correction procedure contingent on incorrect responses. LU instruction was compared to conditions that omitted individual consequence portions of instruction. In the praise-only-for-correct-responses (PC) condition, researchers delivered contingent praise for correct responses and ignored incorrect responses. In the correction-only-for-incorrect responses (CI) condition, researchers ignored correct responses and implemented the correction procedure contingent for incorrect responses.

Experiment 1

Method

Participants

The researcher selected six participants, ranging in age from four to five years old. All but one of the participants were educationally classified as a preschooler with a developmental delay. The six participants attended a privately run, publicly funded preschool for students with and without disabilities in a suburb of a large urban city. The classroom implemented the Comprehensive Application of Behavior Analysis to Schooling (CABAS®) model of instruction. The participants were able to follow multiple step vocal directions, make requests, and vocally respond to others. The participants had mastered prerequisite repertoires such as imitating gross motor actions, orienting to and observing two-dimensional stimuli, and echoing with point-to-point accuracy. The participants' repertoires were assessed using the Early Learner Curriculum and Achievement Record (ELCAR): A CABAS® Developmental Inventory (Greer, et al., 2020) and Verbal Behavior Development Assessment (VBDA).

Teachers' praise functioned as conditioned reinforcers for all participants - evidenced in the ELCAR assessment for listener and speaker responses, in which there were no differences between the percentage and rate of correct responses emitted by the participants in a probe session with the use of tangibles or tokens and praise. Each probe session included one response opportunity to each of the 10 antecedent discriminative stimuli. The researcher delivered tangibles/tokens or praise contingent on correct independent responses based on the respective conditions. Incorrect responses were unconsequated. All participants demonstrated the same rates of correct responses (90% or 100% accuracy) in the assessment of (a) following one- and two-step vocal directions, (b) imitating one- and two-step gross motor actions, (c) pointing to the known visual stimulus in an array of three stimuli (e.g., colors, shapes, and letters), and (d) responding to "wh" questions regarding personal information (e.g., what's your mom's name?), regardless of the use of tokens or praise as reinforcers for independent correct responses.

Andrew and Adam were five-year old males with developmental delays. Tom was a four-year male with developmental delays. Jack was a four-year old typically developing male. Celine and Amy were four-year old females with developmental delays. All the participants had an instructional history that included both 1:1 and group instruction. Specific to this study, the participants all had an instructional history that included positive reinforcement of correct responses and correction procedures of incorrect responses (the learn unit condition, described below). Detailed information regarding the participants' verbal behavior development is outlined in Table 1.

Setting and Materials

The experiment occurred in the participants' respective classrooms. The classroom consisted of nine students, including one typically developing student and eight students with developmental delays, one teacher, and two teaching assistants. The teacher and/or teaching assistants delivered instruction to non-participant students in 1:1 or small group settings while the researchers conducted the study. All instructional responses (for this experiment and during daily instruction) were measured with frequent interobserver agreement checks and rating of teacher accuracy of implementing instruction using the Teacher Performance Rate and Accuracy (TPRA, Ingham & Greer, 1992) tool.

The classroom contained a play area, four small group stations, and a large rectangular communal table. The instruction occurred at the head of the communal table, where the participant sat with the researcher during the instructional sessions and the probe sessions for maintenance skills. The researcher used Microsoft PowerPoint to present the two-dimensional stimuli during the pre- and post-experimental probes and during the instruction. A laptop, data collection sheets, a timer, and pens with black ink were used in the procedure. The sets of educational stimuli used in the learning process and probe sessions for each participant are listed in Table 2 (top).

Measurement

We measured four dependent variables in learning novel AVCDs for each participant. The primary dependent variable was the number of correct responses emitted by the participant in each instructional session. A correct response was defined as the participant pointing to the corresponding visual stimulus within 5 s of the delivery of the antecedent auditory stimulus. An incorrect response was defined as the participant pointing to a different stimulus or not responding within 5 s of the delivery of the antecedent. The correction procedure allowed two independent opportunities to respond correctly, but only the initial incorrect response was recorded for data purposes.

The second dependent variable was the number of trials required by the participant to meet the acquisition criterion for each condition's set of stimuli. We also measured the total duration required by the participant to meet the acquisition criterion for each set of the stimuli in the three conditions. The duration of a session was measured as the time elapsed from the presentation of the first visual comparison array until the end of the consequence of the last trial (e.g., the delivery of praise following the correct response and correction following the incorrect response in the learn unit condition). The total duration was calculated by adding the duration of all sessions until mastery. Additionally, maintenance probes were conducted to measure the number of correct AVCDs during biweekly assessments for up to 6 weeks following the completion of the teaching phase. During maintenance, we recorded correct and incorrect responses in the same manner as during acquisition.

Independent Variable

We conducted a component analysis of skill acquisition consequences. During the learn unit (LU) condition, researchers praised correct responses and implemented a correction procedure contingent on incorrect responses following the antecedent instructions. The correction procedure involved the researcher modeling the correct response and re-delivering the antecedent and allowing the participant the opportunity to independently respond. We compared LU instruction to two dropout component analysis conditions (Ward-Horner & Sturmey, 2010), whereby we omitted consequence portions of instruction. In the praise-only-for-correct responses (PC) condition, researchers applied positive reinforcement operations to correct responses and ignored incorrect responses. In the correction-only-for-incorrect responses (CI) condition, researchers ignored correct responses and implemented the correction procedure contingent on incorrect responses. We manipulated this independent variable with educational stimuli and measured acquisition and response maintenance.

Experimental Design

We used an adapted alternating treatment design (Sindelar, 1985) to study the effects of consequence conditions on the acquisition and maintenance of AVCDs. We paired the participants into three dyads randomly and counterbalanced the assignment of stimulus sets to the three consequence conditions across the dyads. Additionally, the researchers controlled and equated the difficulty level of the educational stimulus sets by limiting the number of syllables contained in each antecedent and types of stimuli (Cariveau et al., 2021). The researchers chose nine novel two-syllable stimuli from each of the two categories, insects and office items according to ELCAR goals, and randomly assigned them to three stimuli sets. None of the stimuli in each set shared the same first syllable. During the instruction, the researchers counterbalanced the daily order of instruction conditions within each dyad and the targets across the three dyads to decrease the possibilities of sequence and carryover effects through this procedure. One instructional session under each consequence condition was conducted for all participants per day. All sessions were conducted before lunch.

Procedure and Data Collection

The procedure was presented in the following order: (a) probe the number of correct auditory-visual conditional discrimination responses for the three sets of educational stimuli, (b) start the instruction across the three consequence conditions, (c) if the participant failed to master the stimuli set in one condition, switch to the more effective learning procedure, and (d) probe the number of correct responses to the stimulus sets during bi-weekly maintenance assessments for up to six weeks.

Pre-experimental probes to identify target stimuli

Prior to the experiment, stimuli were equated and assigned to three sets. The researcher sat next to the participant at a rectangular table and presented two-dimensional stimuli in PowerPoint on a laptop. Each trial included an array of six pictures (three stimuli on top and three at the bottom on a slide), including four target stimuli and two distracter stimuli that were never taught. The position of the target stimuli changed across trials. Sessions included three presentations of each target relation for a total of 12 trials. For each target relation, there were three variations of the picture that corresponded to the discriminative stimulus (e.g., three different pictures of a mantis).

The researcher first conducted probes for speaker responses for each set of stimuli for all participants. If the participant emitted the name of a picture accurately within 5 s following the researcher pointing to a stimulus, we recorded it as a correct response and replaced the target with another stimulus of the same category that was not in the participants' repertoire. The probe procedure for AVCDs was similar to that for the speaker responses, in which the participant was required to point to the target stimulus within 5 s of the researcher presenting the auditory sample stimulus "point to _ (e.g., mantis)". If the participant pointed to a target stimulus correctly during all probe trials, the researcher replaced the target with a novel stimulus of the same category. All probe trials were unconsequated.

Baseline

Following pre-experimental probes three baseline probes were conducted with each participant. The procedure was the same as those used during pre-experimental probes.

General Instructional Procedures

The researcher sat next to the participant at a rectangular table and presented the two-dimensional stimuli on a laptop similar to baseline and probe sessions. The researcher presented the auditory sample stimulus (e.g., “point to [e.g., mantis]”) and varied consequences as a function of the specific condition (described below). Like prior phases, each session included 12 trials (4 distinct stimuli, 3 opportunities for each, 3 versions of pictures). The acquisition criterion for a set of stimuli was set at either 11/12 (92%) accuracy or higher across two consecutive sessions (Tom, Andrew, Jack, Celine, and Amy) or 12/12 (100%) accuracy for one session (Adam). Each day, the researcher ran each of the three learning conditions once and this was continued until the participants met criterion for two conditions to ensure that they had the same amount of exposure to the stimuli before terminating instruction and moving to the maintenance assessments. If the participant met the acquisition criterion for two conditions within 5 sessions, we continued instruction until there were five instructional sessions, to provide more exposures for the third condition. The researcher determined that performance plateaued for the third condition if the participant failed to meet the acquisition criterion with the additional exposures. In the case of performance plateauing in one condition, we applied the “best treatment” (Carroll et al., 2015; Cengher et al., 2015) – or the condition that met the acquisition criterion in the fewest sessions – to that plateaued condition. If the participant required the same number of sessions for both conditions, we decided the best treatment condition randomly by flipping a coin. The acquisition criterion for “best treatment” was set at either 90% (11/12) accuracy or higher across two consecutive sessions or 100% (12/12) accuracy for one session.

Learn unit (LU) instruction. LU instruction consists of three components: presentation of antecedent while the participant is attending, an opportunity for the participant to respond, and the delivery of reinforcement contingent on correct responses and a correction procedure contingent on incorrect responses. If the participant correctly pointed to the target picture within 5 s following the vocal antecedent “point to _ (e.g., mantis)”, the researcher vocally praised the participant’s response (e.g., “Wow, you are right! It is mantis!”). If the participant responded incorrectly or did not respond within 5 s following the antecedent, the researcher implemented a correction procedure, including the researcher’s modeling the correct response once, re-presenting the antecedent, and requiring the participant to identify the target stimulus independently two times. The correct responses emitted by the participant during the correction procedure were unconsequated. The detailed procedure of LU instruction is outlined in Figure 1.

Praise-only-for-correct responses (PC) instruction. PC instruction was identical to LU instruction except that the researcher did not provide any consequences following an incorrect response and continued to present the next trial. The researcher vocally praised the participant’s correct responses.

Correction-only-for-incorrect responses (CI) instruction. CI instruction was the same as LU instruction except that the researcher did not provide any consequences following correct responses and moved on to present the next trial. The researcher implemented the correction procedure following an incorrect response (see above).

Maintenance Probes

The researcher conducted bi-weekly maintenance probes for up to 6 weeks following the instruction. The procedure was identical to that of the baseline probes. Conditions that were subjected to the “best treatment” were omitted from this analysis because the learning history included two teaching conditions.

Interobserver Agreement and Treatment Fidelity

Interobserver agreement (IOA) was collected using the trial-by-trial correspondence on the TPRA form (Ingham & Greer, 1992), in which an observer simultaneously and independently collected data on students’ responses. The observers calculated IOA by comparing each individual trial to determine if each trial was scored the same. The researcher divided the number of agreed trials by the total number of trials then multiplied by 100 to determine IOA. The independent observer collected data for 68.5% of the target identification and baseline sessions, 56.6% of the instructional sessions, and 77.8% of maintenance sessions, all with a mean agreement of 100%.

Treatment fidelity was also collected and measured using the TPRA form (Ingham & Greer, 1992), in which a supervisor observed the sessions and collected data on the extent to which the researcher adhered to all components of a trial as scripted in the experiment procedure. This included rating the accuracy of researchers presenting antecedents, securing attending, and delivering contingent consequences as described in each condition (e.g., no reinforcement such as smiling or nodding following a correct response in the CI condition). The supervisor counted a trial as incorrect if the researcher incorrectly implemented one or more components in the trial. The researcher calculated treatment fidelity by dividing the number of trials implemented correctly by the total number of trials, multiplied by 100. During the baseline for sets of educational stimuli, the supervisor collected data for 37% of pre-probe sessions, 45.3% for instructional sessions, and 77.8% of maintenance sessions, all with average agreements of 100%.

Results and Discussion

Figures 2 and 3 display the number of correct responses emitted by participants during baseline, acquisition, and maintenance across the three instructional conditions. Square data points represent those sessions when a participant's performance met the acquisition mastery criterion. For all participants, baseline responding was at a stable low level ranging from 0 to 4 out of 12 correct responses, which was in the range of chance responding. With the exception of Celine, during all comparisons the praise-only-for-correct-response (PC) condition produced lower accuracy at the time when the participant mastered the learn unit (LU) and correction-only-for-incorrect-response (CI) conditions. The PC condition was switched to the "best treatment" for the remainder of the acquisition phase.

During acquisition, Tom met the acquisition criterion (11/12 across two consecutive sessions) for AVCDs in the LU condition in 3 sessions and responses in the CI condition in 5 sessions (top panel, Figure 2). We switched teaching targets in the PC condition to LU and Tom mastered those targets in 4 additional sessions. During maintenance, Tom responded with 12/12 accuracy in the LU condition and 10/12 in the CI condition at 6 weeks following the termination of instruction. Overall, Tom learned targets in the LU condition in 2 fewer sessions (40% fewer sessions than CI) and had higher maintenance in the LU condition as well. His dyad, Andrew, mastered the AVCDs in the LU condition in 8 sessions and in the CI condition in 5 sessions (38% fewer sessions than LU) (top panel, Figure 3). The PC condition was switched to CI in the “best treatment” and Andrew mastered those targets in 5 additional sessions. Consistent with the results during acquisition, Andrew responded with higher accuracy in the CI condition (12/12) than in the PC condition (4/12) at 6 weeks following the instruction. However, both the LU and CI conditions produced better acquisition than the PC condition for participants in Dyad 1. Both participants in Dyad 2, Jack and Adam, required one fewer session (20% and 17% fewer sessions, respectively) to master the responses under the CI condition than under the LU condition (middle panels, Figures 2 and 3). Specifically, Jack required 4 sessions until mastery (11/12 across two consecutive sessions) in the CI condition and 5 sessions in the LU condition (middle panel, Figure 2). Adam met criterion (12/12 for one session) under the CI condition in 5 sessions and the LU condition in 6 sessions (middle panel, Figure 3). After we switched teaching targets in the PC condition to CI, both participants mastered those targets in 2 additional sessions. During maintenance, both participants responded with slightly higher accuracy level for targets learned under the LU condition: 7/12 in the LU condition and 6/12 in the CI condition at 6 weeks for Jack; 11/12 in the LU condition and 9/11 in the CI condition at 4 weeks for Adam. Celine was the only participant who successfully mastered the stimuli in the PC condition, in which she met criterion after 3 instructional sessions (bottom panel, Figure 2). We decided to continue the instruction after she reached mastery for the PC and LU conditions considering the high level of responding accuracy in the CI condition. Celine mastered (11/12 across two consecutive sessions) the responses in the LU condition in 5 sessions (38% fewer sessions than the CI condition) and in the CI condition in 8 sessions. She responded with 12/12 accuracy in both the LU and CI conditions 6 weeks following the instruction. Her dyad, Amy, required one fewer session (25% fewer sessions) to master the AVCDs in the LU condition (3 sessions) than in the CI condition (4 sessions) (bottom panel, Figure 3). The PC condition was switched to LU in the “best treatment” after five instructional sessions, in which Amy mastered those targets in 10 additional sessions. During maintenance, Amy responded with 9/12 accuracy in the LU condition and 10/12 in the CI condition at 6 weeks following the termination of instruction. Overall, Amy had similar levels on acquisition and maintenance in the LU and CI conditions.

Table 3 shows the total number of instructional trials and the cumulative duration until mastery during acquisition for all participants. All participants required an average of 2 fewer trials (3 % fewer) in the LU condition than in the CI condition. However, the average duration required to master the AVCDs was slightly shorter (0.2 min shorter) in the CI condition than in the LU condition. Specifically, three participants, Tom, Celine, and Amy learned the targets in the LU condition in less time than in CI: 3.1 fewer min for Tom, 2.8 fewer min for Celine, and 0.6 fewer min for Amy. In contrast, Andrew, Jack, and Adam required shorter duration to master the responses in the CI condition than in LU: 7.3 fewer min for Andrew, 0.3 fewer min for Jack, and 0.2 fewer min for Adam. Overall, there is no significant difference in regard to the total duration in learning the educational targets across the LU and CI conditions for all participants.

Summary

The results demonstrated that the LU and CI conditions were both effective in teaching auditory-visual conditional discriminations. For every participant except Celine, the CI and the LU conditions were more effective than the PC. Additionally, there was no consistent difference in the duration between the LU and CI conditions for all participants, suggesting that the LU condition that involved both reinforcement and corrections was not necessarily more effective or efficient than CI on teaching AVCDs. The findings also suggested that the correction procedure may be a necessary component in learning AVCDs since the LU and CI conditions that involved the correction procedure led to the faster acquisition than the PC for five out of six participants. Furthermore, the correction procedure alone was sufficient for 3 out of 6 participants – meaning that the CI condition produced the same or faster acquisition than the LU condition (Ward-Horner & Sturmey, 2010).

Experiment 1 is limited in three aspects. First, participants may have had previous exposure to the educational stimuli used in the study or concurrent exposure, although we ensured that these responses were not targeted during school hours. Thus, we were unable to entirely rule out history as a threat to internal validity. The correct responses emitted by Celine increased from 3/12 during baseline to 10/12 in the first session of instruction in the PC condition. This increase may have resulted from fortuitous guessing; nevertheless, it would help verify the effects of the consequence components of correction procedure and praise by further controlling for target novelty and removing possible threats to internal validity associated with using educationally relevant targets. Secondly, the acquisition criterion was not consistent across the participants. Except for Adam, the mastery criterion was set at 11/12 (92%) accuracy or higher across two consecutive sessions. The criterion was at 12/12 (100%) accuracy for one session for Adam. It would help increase the reliability to compare the total trials and duration in the different conditions across the participants by implementing a consistent mastery criterion. Lastly, the researcher incorrectly included scorpion, a three-syllable stimulus, in the CI condition for Tom and Andrew, the LU condition for Jack, and the PC condition for Amy. It would help verify the effects of the LU, CI, and PC conditions by controlling the number of syllables of all targets. In Experiment 2, we conducted a systematic replication to test the generality and reliability of the findings with three-syllable abstract stimuli to examine within-subject replication in a more controlled study.

Experiment 2

Method

Participants

All participants in Experiment 1 participated in Experiment 2.

Setting and Materials

The sets of abstract stimuli used in the learning process and probe sessions for each participant are listed in Table 2 (bottom). The other materials and settings were identical to those in Experiment 1.

Measurement

We measured the same dependent variables as described in Experiment 1. Due to the school closure from the COVID-19 pandemic, we only collected the maintenance data for up to four weeks following the instruction. The independent variable was identical to Experiment 1 except that participant learned AVCDs to abstract stimuli.

Procedure and Experimental Design

The researcher systematically replicated the procedure in Experiment 1 using abstract symbols for all participants. Targets included nonsense CVCV words and abstract symbols. The procedure was identical to Experiment 1 except that the acquisition criterion was set at 12/12 (100%) accuracy for one session for all participants. The researcher conducted bi-weekly maintenance probes for up to four weeks following mastery. All features of the design were the same as in Experiment 1.

Interobserver Agreement and Treatment Fidelity

Interobserver agreement was collected and reported following the same procedure as in Experiment 1. The independent observer collected data for 61.1% of the target stimuli identification and baseline sessions, 35.1% of the instructional sessions, and 50% of the maintenance sessions, all with a mean agreement of 100%. Fidelity data were recorded during 48.1% the target identification and baseline conditions, 30.7% instructional sessions and 50% of maintenance sessions, all with a mean agreement of 100% accuracy.

Results and Discussion

Figures 4 and 5 display the number of correct responses emitted by participants during baseline, acquisition, and maintenance across the three consequence conditions with the abstract stimuli. During acquisition, Tom mastered (12/12 for one session) the AVCDs in the learn unit (LU) and correction-only-for-incorrect-response (CI) conditions in 7 sessions. After switching teaching targets in the praise-only-for-correct response (PC) condition to CI, Tom mastered those targets in 2 additional sessions (top panel, Figure 4). During maintenance, Tom responded with 10/12 accuracy in the LU and CI condition at 4 weeks following the termination of instruction. There were no differences on the acquisition and maintenance of AVCDs for abstract stimuli across the two conditions for Tom. Similarly, Andrew required the same number of sessions to master the AVCDs in the LU and CI conditions (6 sessions) (top panel, Figure 5). The PC condition was switched to CI in the “best treatment” and Andrew mastered those targets in 4 additional sessions. Due to absence from sickness, we only collected maintenance data for Andrew two weeks following the instruction. He had a similar level of accuracy during maintenance across the two conditions: 11/12 in the LU condition and 12/12 in the CI condition.

Jack also learned the target responses within the same number of sessions in the LU and CI conditions (5 sessions) (middle panel, Figure 4). We switched teaching targets in the PC condition to LU and Jack mastered those targets in 3 additional sessions. During maintenance, Jack responded with slightly higher accuracy level for targets learned under the LU condition: 9/12 in the LU condition and 7/12 in the CI condition four weeks following mastery. His dyad partner, Adam, mastered the AVCDs in the LU condition in 4 sessions and responses in the CI condition in 3 sessions (25% fewer sessions than in LU) (middle panel, Figure 5). He mastered the targets assigned to the PC condition in 2 additional sessions under the best treatment of CI. Due to the school closure under the impact of COVID-19, we only collected maintenance data for up to two weeks for Adam. He responded with 6/12 accuracy in the LU condition and 12/12 accuracy in the CI condition. Celine required one fewer session (25% fewer) to master the responses in the LU condition than CI (bottom panel, Figure 4). She reached the criterion for targets in the PC condition in 2 additional sessions after we switched to PC condition. During maintenance, Celine had 100% accuracy for both conditions four weeks following the instruction. Her dyad partner, Amy, learned the abstract symbols slightly faster in the CI condition: 10 sessions in the LU condition and 8 sessions in CI (20% fewer sessions than LU) (bottom panel, Figure 5). We switched to the CI condition for the targets in the PC condition and Amy mastered those targets in 8 additional sessions. She responded with 6/12 accuracy across both conditions at weeks 4 after the instruction. Overall, both the LU and CI conditions produced better acquisition than the PC condition for all participants. Except for Celine, all participants learned at the same rate or faster in the CI condition than in the LU condition. All participants, except for Jack, demonstrated same or higher level of maintenance in the CI condition than in the

LU condition. Consistent with findings in Experiment 1, there was no evident differences on the acquisition and maintenance of abstract stimuli between the LU and CI conditions.

Table 3 shows the total number of trials and duration until mastery during acquisition for abstract stimuli. All participants required an average of 4 fewer trials (6% fewer) in the CI condition than in the LU condition. Consistently, the average total duration in the CI condition was 1.0 min shorter than in the CI condition. Except for Celine, all participants mastered the targets in the CI condition with slightly shorter duration than in the LU condition: 2 fewer min for Tom, 0.5 fewer min for Andrew, 0.2 fewer min for Jack, 0.9 fewer min for Adam, and 5.6 fewer min for Amy. In comparison, Celine required 3.1 min shorter duration to master the responses in the LU condition than CI. Overall, there is no significant differences on the total number of trials and duration in learning the abstract targets across the LU and CI conditions for all participants.

Summary

Like in Experiment 1, the results of Experiment 2 demonstrated that the LU procedure, which included both praise and correction procedures, did not necessarily lead to faster acquisition and higher maintenance than the CI condition. After controlling for the novelty and history of exposure of the participants with abstract stimuli, all participants required similar or fewer number of trials and shorter duration to master the AVCDs in the CI condition than in the LU condition. Furthermore, the CI procedure was necessary for all participants and sufficient for 5 out of 6 participants. None of the participants successfully mastered the abstract symbols in the PC condition after at least five instructional sessions, whereas all participants reached mastery after switching to the best treatment of either LU or CI. The results suggested that the component of praise was not efficient for learning AVCDs for typically developing and high-functioning preschoolers with developmental delays who functioned on the listener and speaker levels of verbal behavior and had independent mands and tacts. In contrast, the correction procedure was necessary and occasionally sufficient for skill acquisition and maintenance.

General Discussion

This study directly analyzed the component effects of skill acquisition consequences involving praise for correct responses and correction procedures for incorrect responses. Previous research focusing on the effects of correction procedures in DTI usually involved the implementation of differential reinforcement (Carroll et al., 2015, 2018; Jessel et al., 2020; Kodak et al., 2016; McGhan & Lerman, 2013). The results of past studies demonstrated that the package of differential reinforcement and multiple correction procedures (e.g., demonstration, active student response, and multiple response repetition) was effective in teaching new skills (e.g., tact and textual responding) to children with disabilities. Past research also revealed that children demonstrated little improvement when correction was absent in contrast to the obvious improvement when correction procedures and differential reinforcement were present (Kodak et al., 2016; Rapp et al., 2012; Worsdell et al. 2005). This study isolated and compared the effects of corrections for incorrect responses and reinforcement for correct responses in skill acquisition and identified that the correction procedure might be the reason why children learned faster when the instruction involved both correction procedures and differential reinforcement. The critical nature of corrections in the learning process are evident in studies conducted with peer tutoring and observational learning, as well. The researchers (Greer et al., 2004; Neu & Greer, 2019) found that elementary school students with and without developmental delays acquired novel skills (e.g., Korean terms and math problems) faster from observing their peers only receiving contingent corrections to incorrect responses during the LU instruction as compared to observing peers only receiving positive reinforcement following correct responses. The results of current study extended previous findings that the correction procedure is a necessary component in skill acquisition. Since the CI procedure was sufficient for 3 out of 6 participants in Experiment 1 and 5 out of 6 participants in Experiment 2, these findings further suggest that the correction procedure might be sufficient for children similar to those who participated in this study.

The outcomes of current study also extended past research findings on the possible sources of control in correction procedures. The effects of correction procedure on increasing correct responses are commonly viewed as a result of negative reinforcement, such that additional prompted responses are required following the student's emission of an incorrect response before the trial is terminated (Cariveau et al., 2019; Rodgers & Iwata, 1991). However, considering the consistent and overall faster acquisition and higher maintenance level under the CI condition, in which contingent corrections were delivered following incorrect responses and no programmed reinforcers following correct responses (as compared to the LU condition), we hypothesize other sources of stimulus control in addition to negative reinforcement in the correction procedure. Specifically, the modeling of the correct response immediately following an error in the correction procedure might serve a critical function in promoting the transfer of stimulus control in auditory-visual conditional discrimination training.

Interestingly, we did not notice any increase on the emission of problem behaviors for all participants in the CI condition. All participants demonstrated 100% accuracy in attending to the stimuli and following teacher's directions across the conditions. The researchers implemented a class wide independent group contingency throughout a school day to maintain the high levels of compliance of students create a positive environment for learning. If the student made it to the top of the “star station” at the end of the day, he or she could pick a gift from the “magic jar”. At the onset of the study, all participants were able to follow classroom rules independently with 90% accuracy for a 30-min interval. Since all participants in this study were able to sit at the table without emitting any problem behaviors for at least 5 min during academic instructions, positive reinforcement on self-management behaviors during the instruction may be necessary to maintain the appropriate behaviors for less preferred instruction programs (e.g., math) and for children with lower levels of compliance.

This experiment was limited in two aspects. First, due to absences and school closure under the impact of COVID-19, we only collected maintenance data for up to two weeks for Andrew and Adam in Experiment 2. It would help verify the similar or higher effectiveness of CI procedure than the LU instruction on skill maintenance with more data. Secondly, we continued to rotate among the three consequence conditions until the participants met acquisition criterion for two before moving to the maintenance assessments. Although this arrangement ensured that the participants had the same amount of exposure to the stimuli in the instruction, the extra trials to the stimuli after reaching the mastery criterion might lead to higher maintenance levels for the first mastered condition. We may further rule out this possibility by terminating the instruction and entering the maintenance probes for a condition immediately following the mastery. Considering that it is impossible to eliminate chance responding for listener responses (i.e., AVCDs), we observed an overall ascending trend in the praise-only-for-correct-response (PC) condition for Jack, Adam, and Celine in Experiments 1 and 2. Although we ensured that the participants had at least five instructional sessions in the PC condition before the implementation of "best treatment", it would help further verify the necessity of the correction procedure with prolonged instruction in the PC condition without implementing "best treatment". Since all participants had instructional history of LU instruction, such experience might favor the effectiveness of LU instruction and influence the outcomes (Coon & Miguel, 2012). However, all participants in current study demonstrated similar or faster acquisition rates in the CI condition than in the LU condition despite the lack of history with CI instruction. Nevertheless, participants without a history of LU instruction my respond differently to the comparison and future research should replicate the procedure with children with different histories of instruction.

The outcomes of the current study suggest several areas for future research. Since all participants in the study were high functioning with regard to language development (e.g., follow multiple step instructions; independently make requests using full sentences) and had an instructional history of LU instruction, the overall higher effectiveness and efficiency of the CI procedure than LU might be influenced by the participants' high levels of compliance, robust verbal repertoires, and previous exposure to the LU instruction. The generality of the results to children with lower levels of compliance, less robust verbal repertoires, and different instructional histories needed further verification. Future research may also replicate the procedure with multiple instruction programs requiring different responding topographies. The findings in the study also suggested a combined result of positive and negative reinforcement as well as antecedent control in the correction procedure. Future research may further test such hypotheses by conducting component analyses examining the effects of the correction procedures on skill acquisition. Additionally, future research may investigate and compare the effects of LU and CI conditions using other prosthetic reinforcers (e.g., tokens and edibles). Although praise functioned as reinforcers for all the participants in the study, the delivery of highly preferred items following the independent correct responses might lead to higher effectiveness and efficiency in the LU condition. The results would help verify the hypothesis that the correction procedure is both a necessary and sufficient component of LU instruction in skill acquisition. Lastly, since prompting was present in the correction procedure of CI and LU conditions, additional comparisons among error-statement only condition without prompting (McGhan & Lerman, 2013), PC condition, and CI condition may help further assess the role of prompting in skill acquisition. While further research is needed to clarify aforementioned concerns, the results reported herein clearly demonstrated the critical role of the correction procedure in skill acquisition, which provides valuable information for instructors regarding the arrangement of instruction consequences and may in turn effectively facilitate students' learning in diverse educational settings.

Table 1

Detailed information of relevant verbal behavior cusps for all participants

Cusps and Capabilities	Description	Dyad 1		Dyad 2		Dyad 3	
		Tom	Andrew	Jack	Adam	Celine	Amy
Bi-directional Naming (BiN)	BiN allows the learning of word-object relations incidentally without the need of direct instruction. BiN has three levels: Pre-UniN, Uni-directional Naming (UniN), Bi-directional Naming (BiN).	Pre-UniN (listener responses: 50% accuracy; speaker responses: 35% accurary)	UniN (listener responses: 100% accuracy; speaker responses: 0% accuracy)	Pre-UniN (listener responses: 50% accuracy; speaker responses: 5% accuracy)	UniN (listener responses: 80% accuracy; speaker responses: 25% accuracy)	Pre-UniN (listener responses: 50% accuracy; speaker responses: 0% accuracy)	Pre-UniN (listener responses: 60% accuracy; speaker responses: 5% accuracy)
Generalized Imitation (GI)	GI enables the "see-do" correspondence without the need of direct instruction.	90% accuarcy for two-step imitations	100% accuarcy for two-step imitations	100% accuarcy for two-step imitations	100% accuarcy for two-step imitations	100% accuarcy for two-step imitations	100% accuarcy for two-step imitations
Auditory Matching (AM)	AM allows auditory matching to sample (MTS) for speech.	90% accuracy	100% accuracy	100% accuracy	100% accuracy	100% accuracy	70% accuracy
Listener Literacy (Phonemic stimulus control)	Listener literacy enables learning from spoken instructions with or without the presence of visual distractors.	80% accuracy for two-step vocal directions	100% accuracy for two-step vocal directions	100% accuracy for two-step vocal directions	90% accuracy for two-step vocal directions	80% accuracy for two-step vocal directions	100% accuracy for two-step vocal directions
Independent Mand (IM)	IM allows mediating the environment under the condition of deprivation with verbal operants.	90% accuracy using full sentences	100% accuracy using full sentences	100% accuracy using full sentences	100% accuracy using full sentences	80% accuracy using full sentences	100% accuracy using full sentences
Independent Tact (IT)	IT allows recruiting adult social attention under non-verbal stimulus control with verbal operants.	80% accuracy using full sentences	100% accuracy using full sentences	100% accuracy using full sentences	100% accuracy using full sentences	100% accuracy using full sentences	100% accuracy using full sentences
Intraverbal	Intraverbal enables verbally responding to questions in academic and social interactions.	80% accuracy using full sentences	90% accuracy using full sentences	100% accuracy using full sentences	80% accuracy using full sentences	80% accuracy using full sentences	100% accuracy using full sentences
Autoclitics	Autoclitics enables one to describe, qualify, quantify, manipulate, and relate to tacts and mands without direct instruction.	80% accuracy using 1 autoclitic	100% accuracy using 1 autoclitic	100% accuracy using 1 autoclitic	100% accuracy using 1 autoclitic	80% accuracy using 1 autoclitic	100% accuracy using 1 autoclitic

Note. Verbal behavior development includes four metamorphosis stages: pre-verbal, listener, speaker, and joining of listener and speaker (Greer et al., 2017). The level of verbal behavior for all participants is listener and speaker.

Table 2

List of 2D stimuli used in Experiments 1 and 2

Category	Condition	Tom	Andrew	Jack	Adam	Celine	Amy
Educational Stimuli	PC	Set 3: earwig, silkworm, planner, keyboard Non-exemplars: beetle and toner	Set 3: earwig, silkworm, planner, toner Non-exemplars: beetle and keyboard	Set 1: mantis, cricket, puncher, shredder Non-exemplars: beetle and toner	Set 1: mantis, cockroach, stapler, shredder Non-exemplars: beetle and keyboard	Set 2: lacewig, aphid, bookend, puncher Non-exemplars: beetle and shredder	Set 2: scorpion, aphid, bookend, compass Non-exemplars: stink bug and charger
	LU	Set 1: mantis, cricket, puncher, stapler Non-exemplars: beetle and toner	Set 1: mantis, cricket, charger, shredder Non-exemplars: beetle and keyboard	Set 2: scorpion, aphid, binder, keyboard Non-exemplars: beetle and toner	Set 2: termite, aphid, bookend, compass Non-exemplars: beetle and keyboard	Set 3: earwig, silkworm, planner, tonner Non-exemplars: beetle and shredder	Set 3: cockroach, silkworm, planner, tonner Non-exemplars: stink bug and charger
	CI	Set 2: scorpion, aphid, compass, bookend Non-exemplars: beetle and toner	Set 2: scorpion, aphid, compass, bookend Non-exemplars: beetle and keyboard	Set 3: earwig, silkworm, planner, hardware Non-exemplars: beetle and toner	Set 3: earwig, silkworm, planner, hardware Non-exemplars: beetle and keyboard	Set 1: termite, cockroach, charger, hardware Non-exemplars: beetle and shredder	Set 1: termite, beetle, keyboard, shredder Non-exemplars: beetle and stink bug
Abstract Stimuli	PC	Set 5: ℵ(Laku), ⌸ (nebi), ⌿(siga), ⍝ (gogo) Non-exemplars: ꝏ ⍊	Set 5: ℵ(Laku), ⌸ (nebi), ⌿(siga), ⍝ (gogo) Non-exemplars: ꝏ ⍊	Set 6: ✪ (Fitu), (⍚) haha, ⎍ (judo) , ⍢ (beni) Non-exemplars: ꝏ ⍊	Set 6: ψ(Kita), (⍚) haha, ⎍ (judo) , ⍢ (beni) Non-exemplars: ꝏ ⍊	Set 4: ⌘ (Migu), (⌥) nini, ⏀(toku), ⍓ (Funti) Non-exemplars: ꝏ ⍊	Set 4: ⌘ (Migu), (⌥) nini, ⏀(toku), ⍓ (Funti) Non-exemplars: ꝏ ⍊
	LU	Set 4: ⌘ (Migu), (⌥) nini, ⏀(toku), ⍓ (Funti) Non-exemplars: ꝏ ⍊	Set 4: ⌘ (Migu), (⌥) nini, ⏀(toku), ⍓ (Funti) Non-exemplars: ꝏ ⍊	Set 5: ℵ(Laku), ⌸ (nebi), ⌿(siga), ⍝ (gogo) Non-exemplars: ꝏ ⍊	Set 5: ℵ(Laku), ⌸ (nebi), ⌿(siga), ⍝ (gogo) Non-exemplars: ꝏ ⍊	Set 6: ψ(Kita), (⍚) haha, ⎍ (judo) , ⍢ (beni) Non-exemplars: ꝏ ⍊	Set 6: ψ(Kita), (⍚) haha, ⎍ (judo) , ⍢ (beni) Non-exemplars: ꝏ ⍊
	CI	Set 6: ψ(Kita), (⍚) haha, ⎍ (judo) , ⍢ (beni) Non-exemplars: ꝏ ⍊	Set 6: ψ(Kita), (⍚) haha, ⎍ (judo) , ⍢ (beni) Non-exemplars: ꝏ ⍊	Set 4: ⌘ (Migu), (⌥) nini, ⏀(toku), ⍓ (Funti) Non-exemplars: ꝏ ⍊	Set 4: ⌘ (Migu), ⍊ (bubu), ◎(koka), ⍐(fento) Non-exemplars: ꝏ ⩦	Set 5: ℵ(Laku), ⌸ (nebi), ⌿(siga), ꝏ (coco) Non-exemplars: ≑ ⍊	Set 5: ℵ(Laku), ⌸ (nebi), ⌿(siga), ⍝ (gogo) Non-exemplars: ꝏ ⍊

Table 3

Total number of trials and cumulative duration required until mastery in the LU, CI, PC conditions in Experiments 1 and 2

Category	Conditions	Tom		Andrew		Jack		Adam		Celine		Amy		Mean	
		Total Trials	Duration in Min	Total Trials	Duration in Min	Total Trials	Duration in Min	Total Trials	Duration in Min	Total Trials	Duration in Min	Total Trials	Duration in Min	Total Trials	Duration in Min
Educational Stimuli	LU	36*	5.7*	96	14.1	60	8.3	72	11.0	48	8.3	36*	5.6*	58*	8.8
	CI	60	8.8	60*	6.8*	48*	8.0*	60*	10.8*	84	11.1	48	6.2	60	8.6*
	PC	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	36*	4.5*	n/a	n/a	n/a	n/a
Abstract Stimuli	LU	84	14.0	72	10.0	60	8.3	48	6.3	36*	5.7*	120	16.2	70	10.1
	CI	84*	12.0*	72*	9.5*	60*	8.1*	36*	5.4*	48	8.8	96*	10.6*	66*	9.1*
	PC	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Note. LU represents learn unit condition, CI represents correction-only-for-incorrect-responses condition, and PC represents praise-only-for-correct-responses condition. The data in the PC condition were not reported for the participants who failed to meet the acquisition criterion when the researcher arbitrarily terminated the acquisition phase.

Figure 1

General procedure of learn unit (LU) instruction

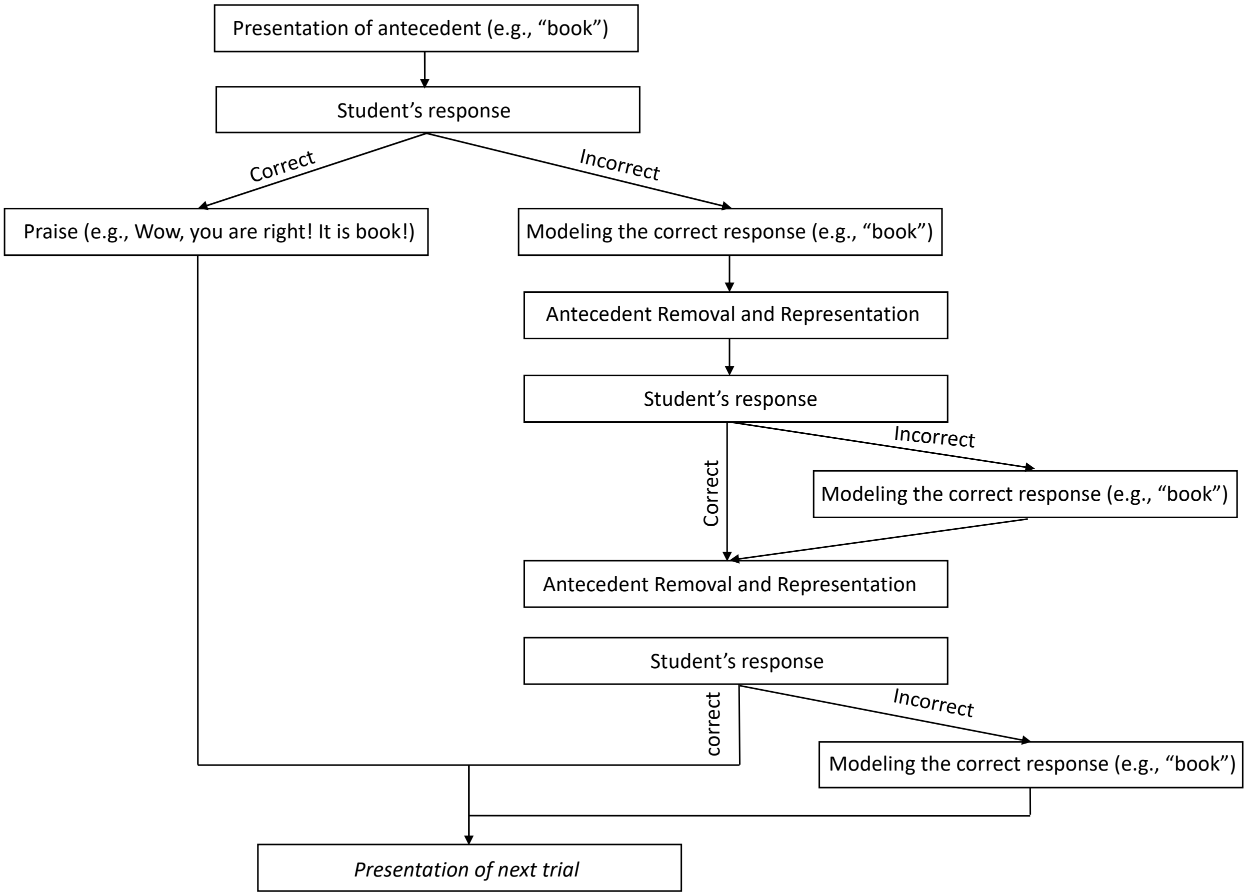
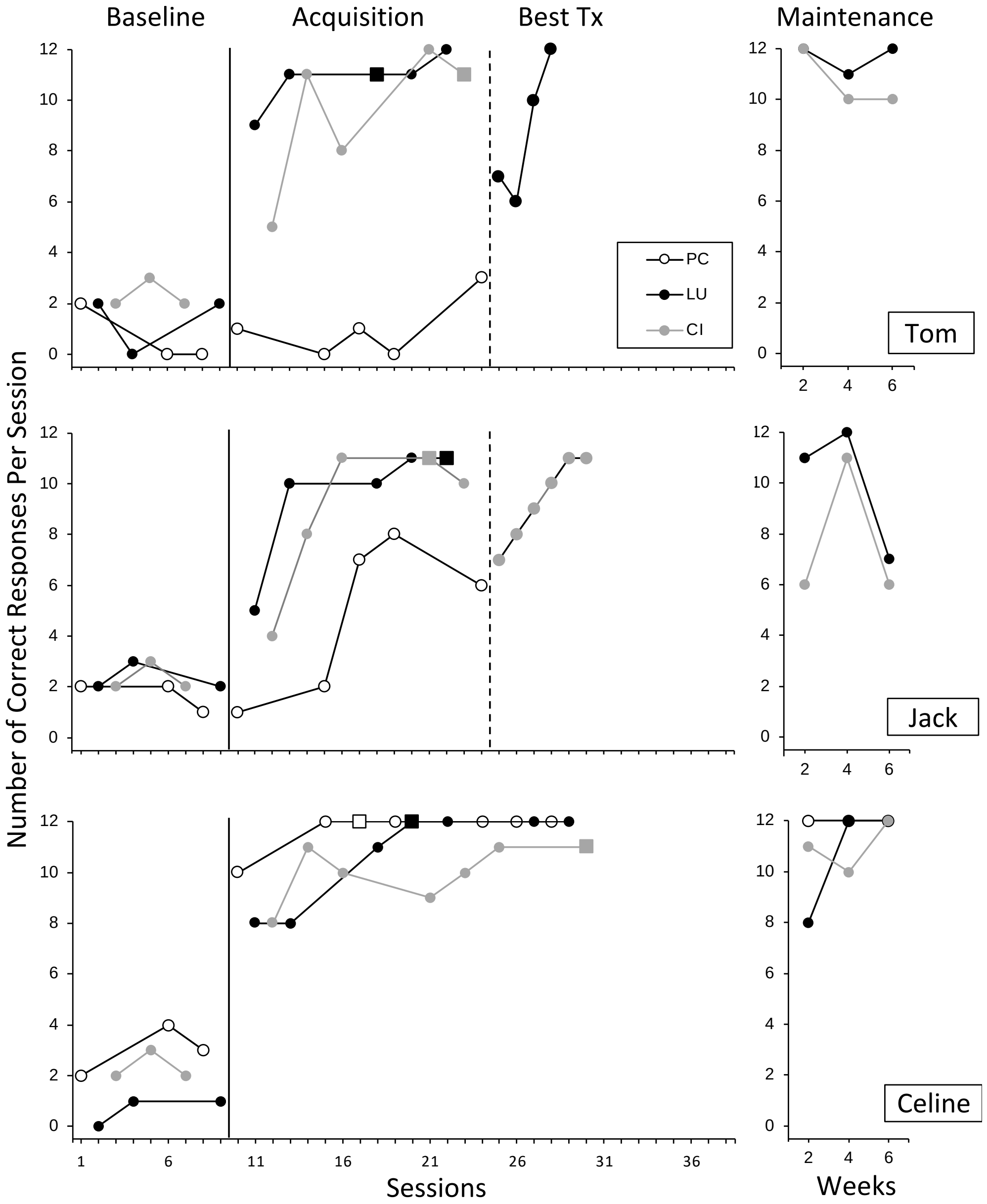


Figure 2

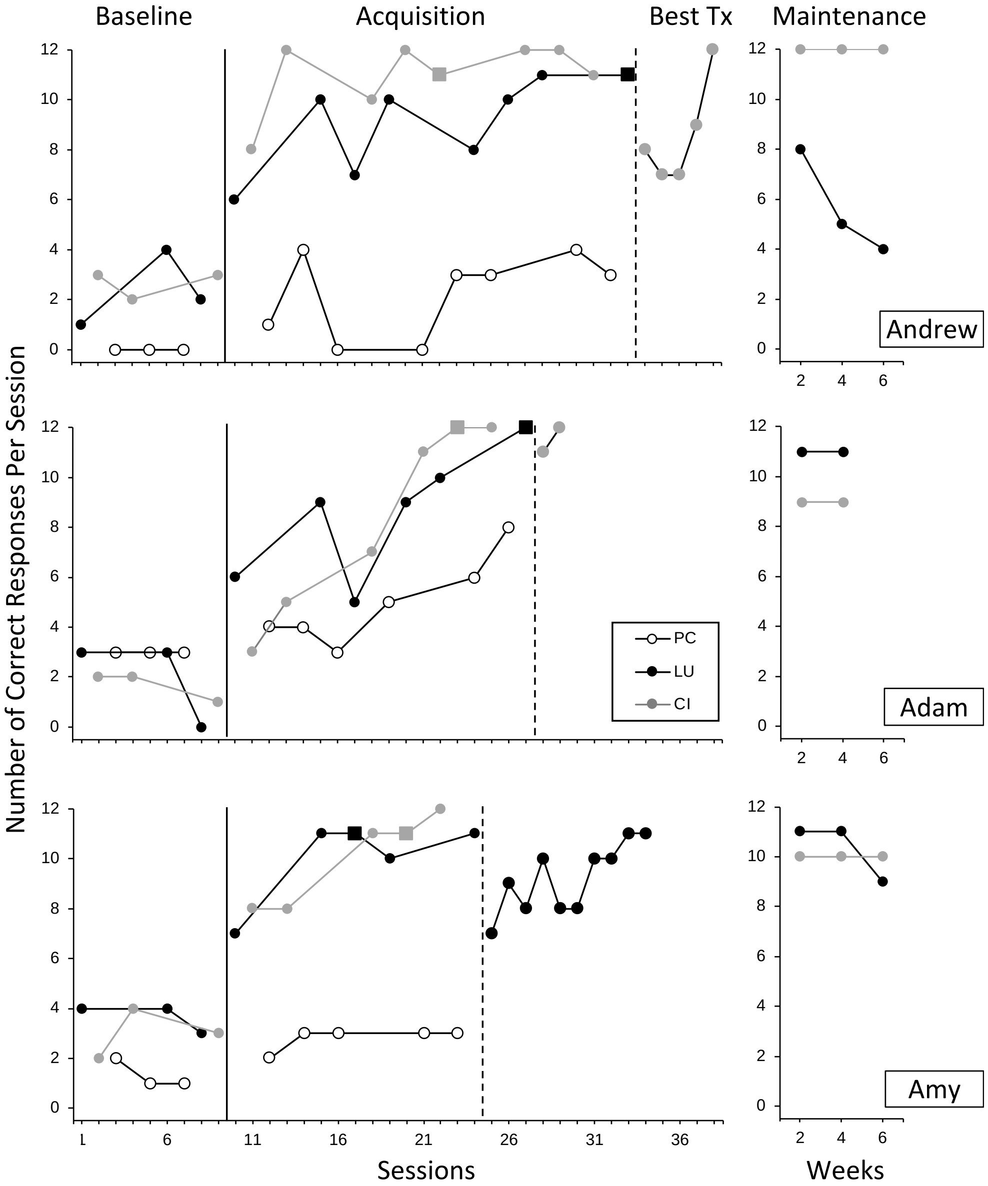
Baseline, acquisition, best treatment, and maintenance data for Tom (Dyad 1), Jack (Dyad 2), and Celine (Dyad 3) with educational stimuli in Experiment 1



Note. Square data points represent sessions where a participant's performance met the mastery criterion.

Figure 3

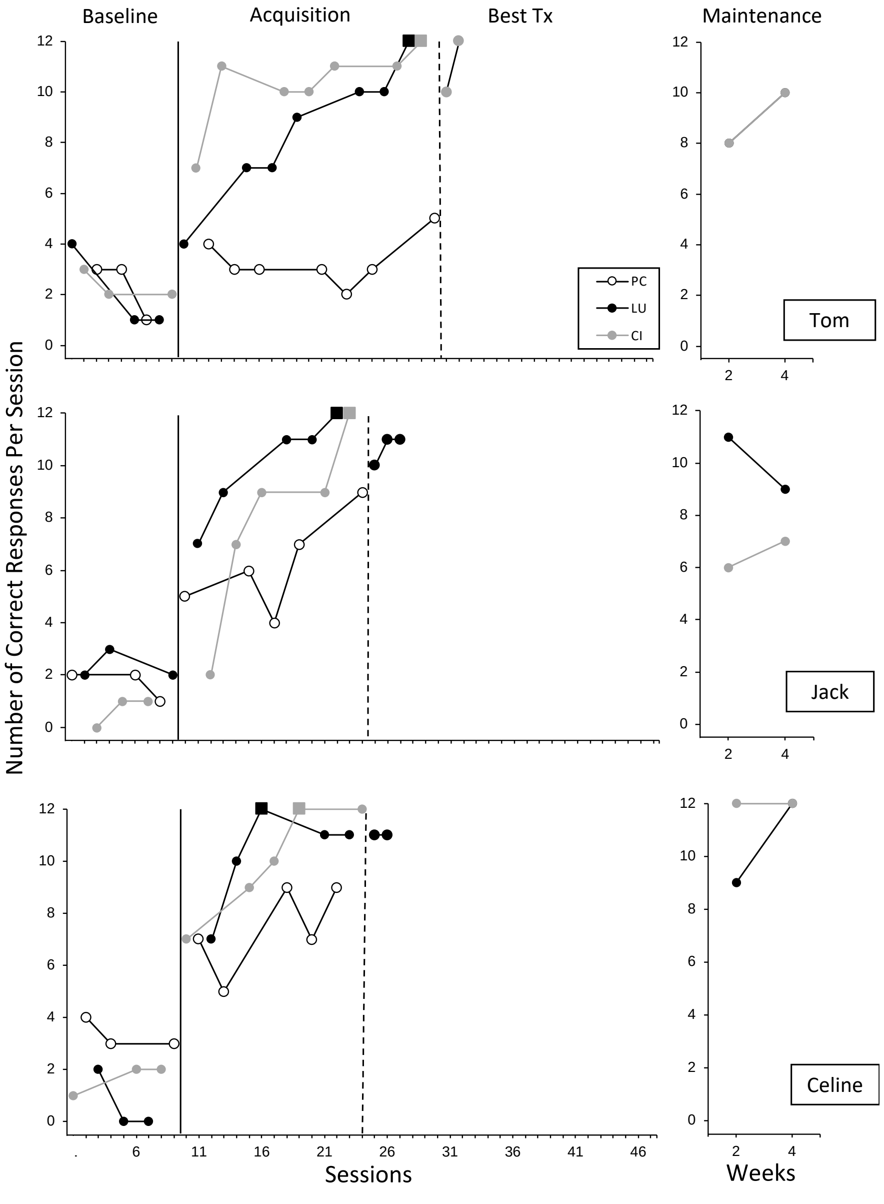
Baseline, acquisition, best treatment, and maintenance data for Andrew (Dyad 1), Adam (Dyad 2), and Amy (Dyad 3) with educational stimuli in Experiment 1



Note. Square data points represent sessions where a participant's performance met the mastery criterion.

Figure 4

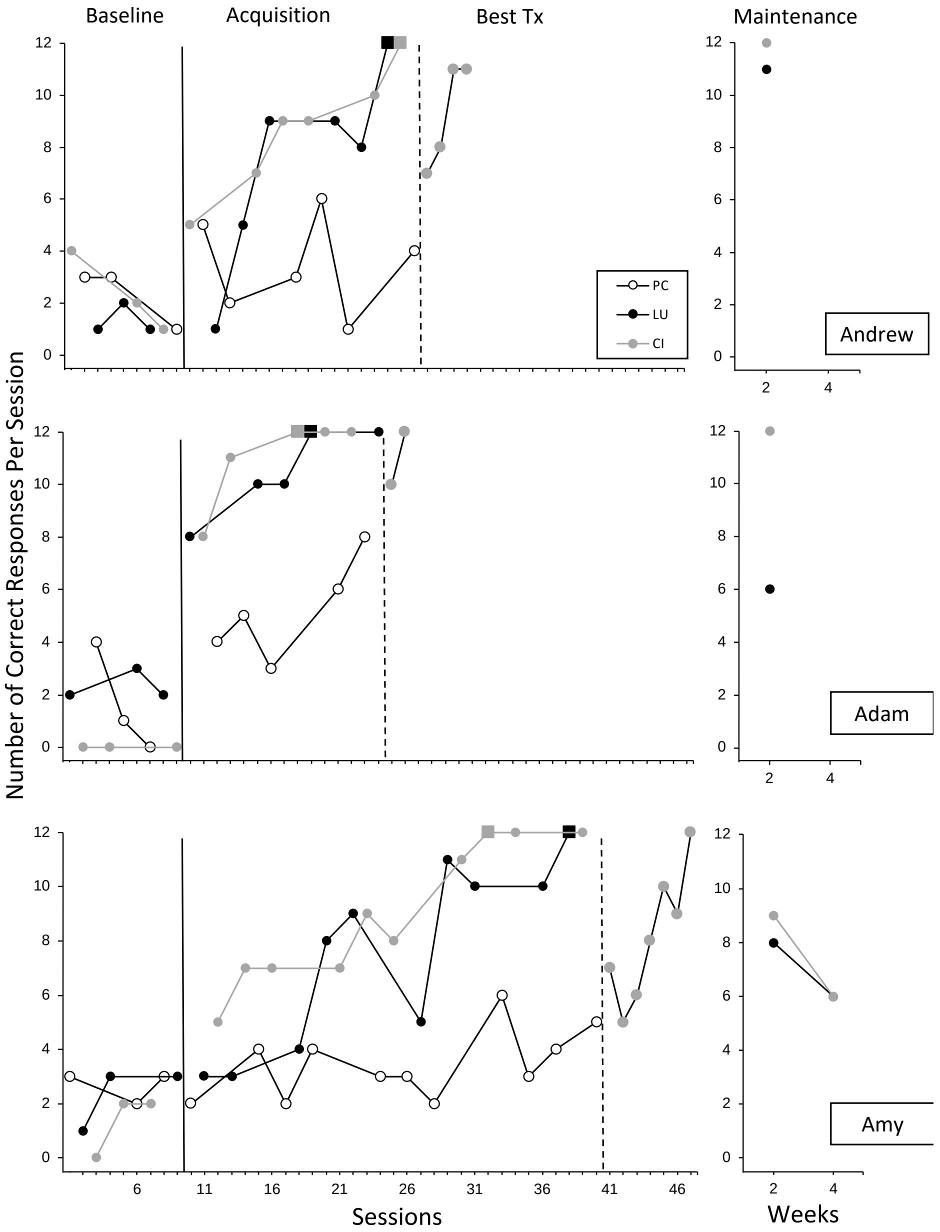
Baseline, acquisition, best treatment, and maintenance data for Tom (Dyad 1), Jack (Dyad 2), and Celine (Dyad 3) with abstract stimuli in Experiment 2



Note. Square data points represent sessions where a participant's performance met the mastery criterion.

Figure 5

Baseline, acquisition, best treatment, and maintenance data for Andrew (Dyad 1), Adam (Dyad 2), and Amy (Dyad 3) with abstract stimuli in Experiment 2



Note. Square data points represent sessions where a participant's performance met the mastery criterion.

Chapter 4

A Comparison of Stimulus Set Sizes:

Systematic Replication with Operant Analysis Acquisition Criteria

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Abstract

We conducted a systematic replication of Kodak et al.'s (2020) and Vladescu et al.'s (2021) experiments on the effects of stimulus set sizes on skill acquisition. The researchers manipulated the stimulus set sizes by teaching three, six, and 12 sight words simultaneously during learn unit instruction. Researchers taught participants until the participant's responding reached the acquisition criterion for 12 different sight words per set size condition. The acquisition criterion was set for an individual operant, whereby when accuracy met criterion for a single sight word, that sight word was replaced in the following session. The results showed that the set-size-three was more efficient than the set-size-six and -twelve in acquisition, which were more consistent with Vladescu et al.'s findings, but not consistent with Kodak et al.'s findings. However, the set-size-twelve reliably produced the highest maintenance levels for all participants. The definition of "effectiveness" based on acquisition or maintenance was discussed.

Keywords: learn unit instruction, stimulus set sizes, operant analysis acquisition criteria, skill acquisition

A Comparison of Stimulus Set Sizes:
Systematic Replication with Operant Analysis Acquisition Criteria

Children with learning disabilities require explicit and intensive academic interventions (National Autism Center, 2015). In special education settings, it is common for teachers to break down long-term objectives into several short-term objectives that drive what single sessions of teaching entail. For example, a long-term objective may be for a child to learn 12 color names at 90% accuracy or higher. From this long-term objective, the teacher may decide on four short term objectives of learning three specific color names at 90% accuracy or higher. Stimulus set size refers to the number of stimuli (e.g., three color names) that teachers and therapists need to teach simultaneously in an instructional/therapy session. Past research on skill acquisition has varied widely regarding the selection of stimulus set sizes, ranging from one to 15 stimuli per session, without providing the rationale for the selection of a stimulus set (Haq et al., 2015; Kodak et al., 2020; Leaf & McEachin, 1999; Lovaas, 2003; Maurice et al., 2001; Yaw et al., 2014). Several curricular manuals for children with disabilities recommended including at least three targets in a stimulus set when learning listener and speaker responses to decrease the probability of the establishment of faulty stimulus control (Greer & Ross, 2008; Greer et al., 2020; Grow & LeBlanc, 2013; LaMarca & LaMarca, 2018; MacDonald & Langer, 2018). However, few researchers have compared the effects of stimulus set size on skill acquisition (Kodak et al., 2020; Vladescu et al., 2021) and research on this variable is important as this variable is included in all skill acquisition studies, regardless of whether one attends to this fact.

Kodak et al. (2020) conducted the first empirical comparison of different stimulus set sizes in the discrete trial instruction (DTI). DTI involves small units of three-term contingencies, including the discriminative stimuli, prompts (as necessary), student responses, contingent consequences, and intertrial intervals (Smith, 2001). Kodak et al. (2020) taught 12 tacts in each of four stimulus set size conditions: teaching three, four, six, and 12 stimuli simultaneously until 12 total tacts met the acquisition criterion. Participants included three children (3- to 6-year-old males) and one adolescent (15-year-old male) diagnosed with autism spectrum disorder (ASD). Each instructional session consisted of 12 trials, including four presentations per stimulus in the set-size-three condition, three presentations the set-size-four condition, two presentations the set-size-six condition, and one presentation the set-size-twelve condition. There were three stages of the tact training: 0-s prompt delay with the criterion of 90% prompted correct responses, 5-s prompt delay with 50% independent correct reinforcement, and 5-s prompt delay with 100% independent correct responses across two consecutive sessions using differential reinforcement. The acquisition criterion was set at 100% independent correct responses across two consecutive sessions. With set sizes of three, four, and six stimuli, meeting criterion with a set signaled moving on to the next set until 12 total tacts met the acquisition criterion. The results showed that all participants required fewer trials and shorter durations to meet the criterion for the tacts assigned to the larger stimulus set sizes (six and 12 stimuli) compared to the smaller set sizes (three and four stimuli). Kodak et al. demonstrated that this overlooked variable affected the speed of acquisition. Nevertheless, the results may have been influenced by the implementation of the same acquisition criterion across different set sizes. For example, participants needed to emit eight consecutive independent correct responses per stimulus to meet criterion in the set-size-three condition (to respond with 100% accuracy across two consecutive sessions), whereas they needed to emit two consecutive independent correct responses per stimulus in the set-size-twelve condition. Thus, the number of independent correct responses required to meet the criterion decreased as the stimulus set size increased (Vladescu et al., 2021). Additionally, since the researchers did not control the number of presentations per stimulus in each session, the results might be due to the unnecessary trials for the smaller set sizes and in turn failed to provide an accurate measurement on the effectiveness of different stimulus sizes.

Kodak et al. (2020) also measured the maintenance accuracy of the acquired tacts across different stimulus set sizes for two weeks following the mastery of a stimulus set. The results showed that all participants demonstrated similar maintenance levels across different set sizes. Specifically, three out of four participants responded at a minimum of 70% accuracy at two weeks following mastery, whereas one participant responded with low accuracy across all conditions. Since the experiment consisted of three prompt fading stages for acquisition, the similar maintenance levels across different sizes might be due to the prolonged exposures across all conditions. Instruction procedures that control the exposures in the tact training may identify the differences of stimulus control strengths across the different set sizes.

Vladescu et al. (2021) conducted a systematic replication for Kodak's results on skill acquisition with two adolescents with ASD and extended the literature by controlling the number of independent correct responses required to meet criterion across the set sizes of three, six, and 12 stimuli in the tact training. In other words, the acquisition criterion was condition-specific according to the difference in the number of presentations per stimulus in an instructional session across the three conditions. Specifically, the acquisition criteria were set at 100% independent correct responses for one session in the set-size-three condition, for two consecutive sessions in the set-size-six condition, and for four consecutive sessions in the set-size-twelve condition. The results showed that the smaller stimulus set sizes (three and six stimuli) were more efficient than the large set size (12 stimuli) on tact acquisition for both participants, with set size of three stimuli produced the fastest tact acquisition for one participant and set size of six stimuli for the other. The results contrasted with the findings of Kodak et al. (2020)'s regarding the efficiency of the small (three stimuli) and large (12 stimuli) stimulus set sizes in skill acquisition. Although Vladescu et al. (2021) controlled the number of independent correct responses required to mastery across different conditions by using condition-specific acquisition criteria, the design did not control the number of presentations per stimulus within a session, such that the number of presentations per stimulus within a session decreased as the set size increased. For example, each session included four presentations per stimulus in the set-size-three condition but only one presentation per stimulus in the set-size-twelve condition. Thus, the higher number of presentations per stimulus per session might lead to the faster acquisition rate in the set-size-three and -six conditions than the -twelve condition.

Since the studies of Kodak et al. (2020) and Vladescu et al. (2021) demonstrated different results, the purpose of this research was to conduct a systematic replication of Kodak et al.'s and Vladescu et al.'s research with further experimental control on the number of presentations per stimulus in each session on skill acquisition. The researchers manipulated the stimulus set-size-three, - six, and -twelve during learn unit (LU) instruction. LU instruction, a type of DTI, interlocks three-term contingencies for both student and teacher. The student's observing responses are discriminative stimuli (SDs) for a teacher to provide antecedents and the student's responses are SDs for a teacher to deliver contingent consequences (Albers & Greer, 1991). Each of the three conditions included learning a total of 12 sight words while simultaneously teaching three stimuli per session, six stimuli per session, and 12 stimuli per session, respectively. Each stimulus was presented three times in each instructional session for session lengths of 9, 18, and 36 trials, respectively.

Additionally, we implemented operant analysis (OA) acquisition criterion (Wong et al., 2021; Wong & Fienup, in press) that targeted the acquisition mastery of individual operant instead of set-based acquisition criteria as used by Kodak et al. (2020) and Vladescu et al. (2021). Most studies focusing on skill acquisition implemented set-based analysis, in which researchers randomized blocks of trials that consisted of multiple operants and presentations of each antecedent (Wong et al., 2021) and evaluate acquisition criteria based on the percentage of independent correct responses across all responses emitted in a session (Grow et al., 2011, 2014; Grow & Van der Hijde, 2017). Since the set-based acquisition mastery criterion depends on the acquisition rate of the slowest operant in a set, the instruction efficiency might be affected if a student acquired an operant much slower than the remaining operants in a set (for an explanation, see Wong et al. 2021). For example, in teaching a total of 12 tacts, researchers needed to deliver four stimulus sets in the set-size-three condition in comparison with one stimulus set in the set-size-twelve condition. Thus, the influence of set-based acquisition criterion on the instruction efficiency was more evident for the smaller set sizes than the bigger set size, since the total number of stimulus sets increased as the set size decreased. The use of OA addressed this problem by setting acquisition criterion per operant, independent of the learning rates of other operants in the same set. If the student learned one operant much slower than the other operants in a set as described in the previous example, we would substitute novel targets for the mastered operants while maintaining the non-mastered operant in an instruction session, without interfering the instruction efficiency.

The goal of this research is to further examine the effects of stimulus set size on the acquisition and maintenance of speaker responses, with the use of operant analysis (OA) acquisition criterion (Wong et al., 2021; Wong & Fienup, in press). In OA, when responding to a single operant meets or exceeds the criterion, that operant is considered “mastered” and is replaced in the following session with a new operant. Since previous studies solely involved participants with ASD, we extended past findings for preschoolers with and without disabilities. The results will help teachers and therapists effectively facilitate students’ learning and making scientifically based decisions regarding the learning goals.

Method

Participants

The researchers selected three participants, ranging in age from 3- to 4-years old participating in the study. Two participants were educationally classified as a preschooler with a developmental delay, one participant possessed no diagnoses. The three participants attended a full-time publicly funded preschool for students with and without disabilities in a suburb of a large urban city. The classroom implemented the Comprehensive Application of Behavior Analysis to Schooling (CABAS$^{®}$) model of instruction. The participants were able to follow multiple-step vocal directions, make requests (mands), label objects (tacts), and vocally respond to others (intraverbals). The participants had mastered prerequisite repertoires such as imitating gross motor actions, orienting to and observing two dimensional stimuli, and echoing with point-to-point accuracy. The participants’ repertoires were assessed using the Early Learner

Curriculum and Achievement Record (ELCAR): A CABAS® Developmental Inventory (Greer, et al., 2020). Teachers' praise functioned as a conditioned reinforcer for all participants. This was examined using the ELCAR assessment, whereby performance behaviors were reinforced using primary reinforcers and praise and no difference in rate of behavior was observed.

Indie was a 4-year-old Black female with developmental delays. Kevin was a 4-year-old White male with developmental delays. Nathan was a 3-year-old White typically developing male. All the participants had an instructional history of learning listener (e.g., pointing) and speaker responses (e.g., tacts) involving set sizes of three, four, and five stimuli in the learn unit (LU) instruction. Detailed information regarding the participants' verbal behavior development is outlined in Table 1.

Setting and Materials

Data were collected in the participant's respective classrooms. The classroom consisted of seven students, including two typically developing students and five students with developmental delays, one teacher, and one teaching assistant. The teacher and/or teaching assistant delivered instruction to non-participant students in 1:1 or small group settings while the researchers conducted the study. We measured all instructional responses during the daily instruction (including this experiment) with frequent interobserver agreement checks and rating of teacher accuracy of implementing instruction using the Teacher Performance Rate and Accuracy (TPRA, Ingham & Greer, 1992) assessment tool.

The classroom contained a play area, four small group stations, and a large rectangular communal table. The researcher and the participant sat across the head of the communal table during the intervention sessions and the probe sessions for maintenance skills. The researcher used Microsoft PowerPoint to present the sight words during the pre- and post-intervention probes and during intervention. Each sight word was displayed in three different fonts (Abadi, Calibri Light, Courier) randomized with three different colors (black, blue, red) in 130-point font. A laptop, data collection sheets, a timer, and pens with black ink were used in the procedure. The sets of sight words used in the learning process and probe sessions for each participant are listed in Table 2. The details regarding the assignment of the sets of stimuli to each condition are listed in Table 3.

Measurement

We measured four dependent variables in the learning of novel sight words for each participant. A correct response in a trial was defined as the participant's textually responding to the word accurately within 5 s of the presentation of the antecedent visual stimulus. An incorrect response in a trial was defined as the participant's emitting the word inaccurately or not responding within 5 s of the presentation of the word. Considering that the acquisition mastery criterion was set for an individual word (Wong et al., 2020) and the number of trials per session was different across conditions, we measured the participants' performance by the cumulative number of stimuli mastered with respect to the cumulative trials in an instructional session. The cumulative words mastered in a session was calculated by adding the number of words mastered in the current session with the total number of words mastered in the previous sessions. The cumulative trials delivered in a session was calculated by multiplying the total number of sessions delivered (including the current session) by the respective number of trials per session in each condition (i.e., 9 trials in the set-size-three condition, 18 trials in the set-size-six condition, and 36 trials in the set-size-twelve condition).

The second dependent variable was the total number of adjusted and unadjusted instructional trials required by the participant to meet criteria for all the 12 words in each condition. Since the words mastered in the previous sessions were delivered with non-mastered words in an instructional session when there was no new word to replace the mastered words in a condition, the trials to the mastered words in a session were unnecessary trials. We adjusted the total number of trials required to master 12 words across conditions by excluding the trials delivered to the words that were mastered in the previous sessions.

We also measured the adjusted and unadjusted total duration required by the participant to meet criterion for the 12 sight words in each of the three conditions. The duration of a session was measured as the time elapsed from the presentation of the first word until the end of the consequence of the last learning opportunity (i.e., the delivery of praise following the correct response and correction following the incorrect response). The unadjusted total duration was calculated by adding the duration of all sessions until the mastery of 12 words. We adjusted the total duration until the mastery of 12 sight words by dividing the adjusted total number of trials by the unadjusted total number of trials and multiplying by the unadjusted total duration. Additionally, maintenance probes were conducted to measure the number of correct responses in each condition every 10 days for up to 30 days following the mastery of a word. During maintenance, the correct and incorrect responses were recorded in the same manner as during acquisition.

Independent Variable

We compared the participants' skill acquisition and maintenance with different stimulus set sizes in the learn unit (LU) instruction. The researchers praised correct responses and implemented a correction procedure contingent on incorrect responses following the antecedent instructions. The correction procedure involved the researcher modeling the correct response and re-delivering the antecedent and allowing the participant the opportunity to independently respond two times. Each of the three conditions included a total of 12 sight words with simultaneous teaching of three stimuli per session (set-size-three), six stimuli per session (set-size-six), and 12 stimuli per session (set-size-twelve). Each stimulus was presented three times in each instructional session, resulting in 9, 18, and 36 trial sessions per condition, respectively.

Experimental Design

We used an adapted alternating treatment design (Sindelar, 1985) to investigate the effects of stimulus set sizes on skill acquisition and maintenance. The researchers randomly decided the order of the participants and counterbalanced the assignment of stimulus sets to the three conditions across the participants, such that all participants had different stimuli sets in each condition (see Table 3). Additionally, the auditory and visual characteristics of the words were controlled in each set, such that none of the words in a set shared the same first syllable, rhyming with each other, or looked similar (Cariveau et al., 2021; Gast, 2020). We selected 36 novel one-syllable sight words and randomly assigned them to three stimuli sets. During the acquisition, we counterbalanced the daily order of instruction conditions across the three participants to decrease the possibilities of sequence and carry-over effects through this procedure. The participants engaged in a different activity (e.g., free play, coloring, and writing letters) for at least 10 min between any two intervention sessions. At least one intervention session (at most 3 sessions) for each set size condition was conducted for all participants per day, all before lunch.

Procedure and Data Collection

The procedure was presented in the following order: (a) Probe the number of correct responses for the three sets of sight words, (b) start the instruction across the three conditions, and (c) probe the number of correct responses to the mastered words in the maintenance assessment every 10 days for up to 30 days.

Pre-experimental probes to identify target stimuli

Prior to the experiment, we assigned the words to the stimuli sets (see Experimental Design section above) and conducted probes to identify the sight words not in the participant's repertoire. The researcher sat across the participant at a rectangular table and presented the words in PowerPoint on a laptop. Each probe session included one presentation of each word for a total of 12 trials. We presented each stimulus on the laptop for 5 s and moved on to next stimulus. All probe trials were unconsequated. A word was included if no correct response was emitted during this probe. If the participant textually responded to a word correctly, the word was replaced with another word and the replacement word was then tested.

Baseline

After identifying stimuli that were not in a participant's repertoire and determining formal sets of stimuli, we conducted three probe sessions for the number of correct responses emitted by all participants to each of the three sets of 12 words. The procedure was the same as that of pre-experimental probes. Responses were unconsequated during baseline sessions.

General Instructional Procedures

The researcher sat across the participant at a rectangular table and presented the sight words on a laptop. We implemented learn unit (LU) instruction in the intervention, which consists of three components: presentation of antecedent while the participant is attending, an opportunity for the participant to respond, and the delivery of contingent consequences. The researcher recorded the occurrences of correct and incorrect responses as well as session duration. In each session, three variations of the words that corresponded to the discriminative stimulus (different fonts and colors of a word) were rotated in a random order. The researcher presented discriminative stimuli (e.g., sight word "book"), vocally praised the correct responses and implemented a correction procedure for incorrect responses. For the correction procedure: (a) the researcher modeled the correct response, (b) required the participant's echo/imitation once, (c) re-presented the antecedent, and (d) required the participant to textually respond to the word independently. If the participant emitted the sight word correctly in step (d), the researchers immediately repeated the steps (c) and (d). If the participant emitted the sight word incorrectly or did not respond in step (c), the researchers repeated steps (a), (b), (c) and (d) and presented next stimulus. The correct responses emitted by the participant during the correction procedure were unconsequated. The acquisition criterion was set at 100% accuracy for a single word in one session. The detailed instruction procedure is outlined in Figure 1.

Set-size-three. Each session consisted of nine trials, including three presentations for each of the three words. If the participant met the acquisition criterion for a word in a session, the researchers replaced this word with a novel word in the corresponding word set. We continued this process until the participants mastered the assigned 12 words.

Set-size-six. This condition was identical to the set-size-three condition except that each session consisted of 18 trials, including three presentations for each of the six words.

Set-size-twelve. This condition was the same as set-size-three except that each session consisted of 36 trials, including three presentations for each of the 12 words. Because each session simultaneously taught all words in the set, there was no replacement of word that met the acquisition criterion. Rather, we continued teaching all 12 words simultaneously until accuracy on all 12 words met the acquisition criterion.

Maintenance Probes

The researchers conducted maintenance probes every 10 days for up to 30 days following the mastery of a word. The procedure was identical to that of the baseline probes except that the researchers only presented the mastered words in each condition.

Interobserver Agreement and Treatment Fidelity

An observer simultaneously and independently collected data on students' responses while the researcher conducted the experiment. The trial-by-trial correspondence was compared at the end of each session. The Interobserver agreement (IOA) was calculated by comparing each individual trial to determine if each trial was scored the same. The researcher divided the number of agreed trials by the total number of trials then multiplied by 100% to determine IOA. The independent observer collected data for 100% of the target identification and baseline sessions, 59.4% of the instructional sessions, and 84.9% of maintenance sessions, all with a mean agreement of 100%.

Treatment fidelity was collected and measured using the TPRA form (Ingham & Greer, 1992). A supervisor observed the sessions and collected data on the extent of the researcher's adherence to the experiment procedure, including the accuracy of the researcher's presenting antecedents, securing the attending, and delivering contingent consequences. A trial was determined as incorrect if the researcher incorrectly implemented one or more components in the trial. The researcher calculated treatment fidelity by dividing the number of correctly implemented procedure components by the total number of components, multiplied by 100%. The supervisor collected data for 100% of baseline, 48.8% of instructional sessions, and 74.6% of maintenance sessions, all with average fidelity of 100%.

Results

Figure 2 displays the cumulative number of sight words mastered by the participants with respect to the cumulative number of instructional trials and the number of correct responses during maintenance probes. The baseline data remained stable at 0 for all participants. All participants successfully mastered the 12 sight words assigned to the conditions of set-size-three, -six, and -twelve. During acquisition, Indie met the acquisition criterion (100% accuracy per operant in one session) for all set-size-three words in 261 trials (top panel, Figure 2). She required 99 additional trials (37.8% more trials) in the set-size-six condition and 603 additional trials (231.0% more trials) in the set-size-twelve condition. Indie responded with 0/12 accuracy in the set-size-three condition, 4/12 in the set-size-six condition, and 9/12 in the set-size-twelve condition, at 30 days following mastery. Kevin met the acquisition criterion for all set-size-three words in 198 trials. He required 144 additional trials (72.7% more trials) in the set-size-six condition and 558 additional trials (281.8% more trials) in the set-size-twelve condition. Due to Kevin’s dropping out of school under the impact of COVID-19, we only collected maintenance data for up to 10 days for Kevin. He responded with 9/12 accuracy in the set-size-three and -six conditions and 12/12 accuracy in the set-size-twelve condition. Nathan met the acquisition criterion for all set-size-three words in 261 trials. He required 261 additional trials (100% more trials) in the set-size-six condition and 593 additional trials (231.0% more trials) in the set-size-twelve condition. During maintenance, Nathan responded with 2/12 accuracy in the set-size-three condition, 6/12 in the set-size-six condition, and 9/12 in the set-size-twelve condition, at 30 days following mastery. Overall, all participants required fewer trials to master all words in the set-size-three condition than in the set-size-six and -twelve conditions. However, the highest maintenance outcomes were reliably observed during the set size 12 condition for all three participants.

Figure 3 shows the adjusted and unadjusted total number of instructional trials and total minutes required until mastery during acquisition for all participants. Prior to adjustment, all participants required the fewest trials and minutes to master the sight words assigned to the set-size-three condition followed by the set-size-six and -twelve conditions. After adjustment, the total number of trials and total duration required to master the 12 sight words decreased across all conditions for all participants, especially for the set-size-twelve condition followed by the set-size-six and -three conditions. Nevertheless, the set-size-three condition consistently produced the fastest acquisition of 12 sight words for all participants, prior to and post adjustment. Except for Kevin, all participants required fewer trials and the same or fewer minutes until mastery in the set-size-six condition than the set-size-twelve condition after excluding the unnecessary trials and adjusting the total duration. Post adjustment, Indie met the acquisition criterion for 12 sight words with 213 trials and 29.2 min in the set-size-three condition (top panels, Figure 3). She required 90 additional trials (42.3% more trials) and 12.1 more min (41.4% more min) in the set-size-six condition and 204 additional trials (95.8% more trials) and 16.2 more min (55.5% more min) in the set-size-twelve condition (top left panel, Figure 3). Kevin met the acquisition criterion for 12 sight words with 186 trials and 29.6 min in the set-size-three condition (middle panels, Figure 3). He required 111 additional trials (59.7% more trials) and 20.1 more min (67.9% more min) in the set-size-six condition and 93 additional trials (50.0% more trials) and 2.4 more min (8.1% more min) in the set-size-twelve condition. Unlike in Figure 2, after adjustment Kevin met the acquisition criterion with 18 fewer trials (6.1% fewer trials) and 17.7 fewer min (35.6% fewer min) in the set-size-twelve condition than in the set-size-six condition. Nathan met the acquisition criterion for 12 sight words with 249 trials and 44.5 min in the set-size-three condition (bottom panels, Figure 3). He required 162 additional trials (65.1% more trials) in the set-size-six condition and 201 additional trials (80.7% more trials) in the set-size-twelve condition. Nathan required 22.3 more min (50.1% more min) in the set-size-six and -twelve conditions. Overall, after adjustment all participants learned the targets with an average of 121 more trials (56.0% more trials) and 18.2 more min (52.8% more min) in the set-size-six condition and with 166 more trials (76.9% more trials) and 13.6 more min (39.6% more min) in the set-size-twelve condition than in the set-size-three condition (*M* total trials = 216, *M* total duration = 34.4 min).

Discussion

This study systematically replicated Kodak et al.’s (2020) and Vladescu et al.’s (2021) research with operant analysis (OA) acquisition criterion (Wong et al., 2021). The results showed that the set-size-three was consistently more efficient than the set-size-twelve in terms of acquiring new operants prior to and post the adjustment of the instructional trials and duration, which is more consistent with Vladescu et al.’s findings. Based on the acquisition data, our results contrasted with Kodak et al.’s findings that the larger set-size-twelve was more efficient than the small set-size-three in skill acquisition. Furthermore, while Kodak et al. found no differences on the number of independent correct responses across different set sizes at two weeks following the mastery, our results showed that the set-size-twelve condition reliably produced the best maintenance levels (an average of 75% accuracy) followed by the set-size-six (an average of 42% accuracy) and -three (an average of 8% accuracy) for all participants at 30 days following the intervention. The opposing acquisition and maintenance results for small set-size (e.g., three stimuli) and large set-size (e.g., 12 stimuli) in current study suggest one might choose set sizes based on different instruction goals. If the goal is on the rate of skill acquisition, the small set size (e.g., three stimuli) is more effective; if the goal is on the level of skill maintenance, the larger set size (e.g., twelve stimuli) is more effective.

Several curriculum manuals on skill acquisition for children with disabilities recommended including at least three stimuli in a stimulus set on learning listener and speaker responses (Greer & Ross, 2008; Greer et a., 2020; Grow & LeBlanc, 2013; LaMarca & LaMarca, 2018; MacDonald & Langer, 2018). The involvement of multiple stimuli in a set help distinguish the essential characteristics of a stimulus to establish stimulus control. The results in this study extended past findings and identified that the set-size-three was more efficient than the larger set size-six and -twelve on learning speaker responses. However, the maintenance outcomes question whether efficiency of initial acquisition should be the comparison researchers make (Wolery et al., 1991). A core goal of ABA is to produce durable behavior change (Baer et al., 1968) and the data reported in this study demonstrated that effectiveness and efficiency during acquisition phases do not correlate with the durability of responding (maintenance assessments). Similar outcomes have been demonstrated in studied evaluating acquisition performance criteria.

For example, Fuller and Fienup (2018) taught children academic responses until performance was 50%, 80%, or 90% accurate or higher and found (a) children took longer to meet acquisition criterion at higher levels, and (b) only higher acquisition criteria were associated with high levels of behavior three- to four-weeks after teaching. Thus, we suggest the skill acquisition rates as measures of efficiency for an instruction procedure, whereas the skill maintenance levels - how well and how long a student can maintain an acquired skill - as measures of effectiveness.

Most researchers focusing on skill acquisition administered set-based acquisition criteria, such that the acquisition mastery was evaluated by the percentage of independent correct responses across all responding opportunities to the operants in a blocked set (Grow et al., 2011, 2014; Grow & Van der Hijde, 2017). Kodak et al. (2020) administered a consistent set-based acquisition criterion (100% independent correct responses across two consecutive sessions) across different set sizes. Since in an instructional session each stimulus was presented more times in the smaller set sizes (e.g., four times per stimulus in the set-size-three condition) than in the bigger set sizes (e.g., one time per stimulus in the set-size-twelve-condition), participants needed to emit more independent correct responses to meet the criterion for smaller set sizes than the bigger set sizes. Vladescu et al. (2021) further equated the number of independent correct responses required until mastery across different set sizes through the implementation of condition-specific set-based acquisition criteria. Nevertheless, the mastery for acquisition with set-based analysis relied on the acquisition rate of the slowest operant in a set (Wong et al., 2021). Controlling for the total stimuli to acquire (e.g., 12 stimuli), the implementation of set-based acquisition criterion might affect the instruction efficiency, especially for the smaller set sizes, since the numbers of sets increased as the stimulus set size decreased (e.g., four sets for the set-size-three condition, two sets for the set-size-six condition, and one set for the set-size-twelve condition). The more the stimulus sets involved, the higher probability the instruction efficiency might be affected because the student cannot move on to the next set until he or she masters all the operants in the current set. We controlled the influences on the instruction efficiency from the operants in a set with the use of operant analysis (OA) acquisition criterion (Wong et al., 2021) that targeted the acquisition mastery of individual operant.

We also extended past research by equating the number of presentations per stimulus in a session across different conditions with OA acquisition criterion. Kodak et al.'s (2020) and Vladescu et al.'s (2021) studies involved different numbers of presentations per stimulus in an instructional session across different set sizes (e.g., four presentations per stimulus in the set-size-three condition and one prestation per stimulus in the set-size-twelve condition), in which the number of presentations per stimulus decreased as the stimulus set size increased. The higher efficiency of the bigger stimulus set sizes might be due to the more unnecessary trials for the mastered words in the smaller set sizes. Such overestimation on the total number of trials required to master the smaller set sizes might be more evident in Kodak et al.'s study because of the implementation of the same set-based acquisition criterion across different set sizes (see explanation in the previous paragraph). The fastest acquisition rate of set-size-three for all participants in current study confirmed the aforementioned concerns.

This experiment was limited in a few aspects. First, due to the student's dropping out of school under the impact of COVID-19, we only collected maintenance data for up to 10 days for Kevin. It would help verify the higher levels of correct responding during maintenance in the set-size-six and -twelve conditions than the set-size-three condition with more data. Second, we did not replicate the procedures with novel sets of sight words for participants. Although all participants acquired the sight words in the set-size-three condition with fewer number of trials and shorter duration than in the set-size-six and -twelve conditions, it would help increase the reliability of the results with more data. Since we used a static set of 12 words in each condition, the participants were exposed to all the 12 words throughout the intervention in the set-size-twelve condition because there was no word to replace the mastered words. According to the findings in neuroscience, overlearning (i.e., additional practice of a skill after reaching the acquisition mastery criterion; see Dougherty & Johnson, 1996) enhanced skill retention by abruptly changing the neurochemical processing in humans to rapidly and strongly stabilize the learning state against subsequent new learning (Shibata et al., 2017). Thus, the higher maintenance level in the set-size-twelve condition may be a result of the more overlearning trials to the 12 words in the instruction. That is, during the set-size-three and -six conditions, once a word was mastered, it was removed from teaching until there was no new word to replace the mastered word; however, with the set-size-twelve it continued to be part of instruction until all 12 words were mastered. Continued analysis with further control on the overlearning trials per stimulus across conditions would help verify the higher maintenance levels in the size of 12 condition. Last, the duration per session was recorded in the experiment instead of the duration per trial. We assumed that the ratio of the adjusted total duration to the unadjusted total duration was proportional to the ratio of the adjusted total trials to the unadjusted total trials. Since the duration of vocal praise to a mastered word was shorter than the duration of correction procedure to a non-mastered word, the duration per trial for the words mastered in the previous sessions should be shorter than for the non-mastered words. Thus, our calculation underestimated the actual total duration across all conditions, especially for the set-size-twelve, because the unnecessary trials that were excluded in the set-size-twelve condition were the most for all participants (Figure 3). The same adjusted total duration in the set-size-six and -twelve conditions for Nathan might be due to the bigger underestimation in the set-size-twelve than the set-size-six condition. This underestimation of the total duration did not affect the efficiency of set-size-three because it consistently produced the shortest total duration prior to and post the adjustment and with the least unnecessary trials. Nevertheless, it would help verify the acquisition efficiency in the set-size-six and -twelve conditions by recording the duration per trial.

The outcomes of current study suggest several areas for future research. Since previous and current studies focused on the effects of stimulus set sizes for speaker responses (e.g., tact), the generality of the results to multiple instruction programs requiring different responding topographies (e.g., listener responses) needed further verification. Future research may also replicate the procedure with more participants with different ages and language development levels. Considering the influence of the more overlearning trials per stimulus in the set-size-twelve condition on the maintenance levels, future researchers may involve dynamic sets of stimuli across different set sizes with OA acquisition criteria, such that the mastered stimulus will be replaced with a novel stimulus until the participant masters all the predetermined stimuli in a set. The results would help verify the higher maintenance levels in the set-size-twelve condition. Additionally, the results reported herein suggested measuring the “effectiveness” of different instruction procedures according to the corresponding effects on the maintenance levels rather than the acquisition rates as commonly used in the research on skill acquisition. Although all participants acquired the sight words fastest in the set-size-three condition, the maintenance level was the lowest (0% accuracy for Indie and 17% accuracy for Nathan) in the set-size-three condition at 30 days following the mastery. In contrast, although all participants required more trials and longer duration to master the targets in the set-size-twelve condition than the set-size-three, they demonstrated much higher levels of accuracy in the maintenance probes: 75% accuracy at 30 days following mastery for Indie and Nathan; 92% accuracy at 10 days for Kevin. Considering the opposite results between the skill acquisition and maintenance for small and large stimulus set sizes, we suggest future research to further discuss the definition of effectiveness and efficiency in learning novel skills (Wolery et al., 1991). While further research is needed to clarify the aforementioned concerns, the results reported herein clearly demonstrated the higher efficiency of set-size-three than the set-size-six and -twelve in skill acquisition. These results provide valuable information for instructors regarding the arrangement of instruction antecedents and may in turn effectively facilitate students' learning in diverse educational settings.

Table 1

Detailed information of relevant verbal behavior cusps for all participants

Cusps and Capabilities	Description	Participants		
		Indie	Kevin	Nathan
Bi-directional Naming (BiN)	BiN allows the learning of word-object relations incidentally without the need of direct instruction. BiN has three levels: Pre-UniN, Uni-directional Naming (UniN), Bi-directional Naming (BiN).	Pre-UniN (23% accuracy)	Pre-UniN (20% accuracy)	Pre-UniN (30% accuracy)
Generalized Imitation (GI)	GI enables the "see-do" correspondence without the need of direct instruction.	100% accuarcy for two-step imitations	100% accuarcy for two-step imitations	100% accuarcy for two-step imitations
Auditory Matching (AM)	AM allows auditory matching to sample (MTS) for speech.	100% accuracy	95% accuracy	97% accuracy
Listener Literacy (Phonemic stimulus control)	Listener literacy enables learning from spoken instructions with or without the presence of visual distractors.	100% accuracy for two-step vocal directions	100% accuracy for two-step vocal directions	100% accuracy for two-step vocal directions
Independent Mand (IM)	IM allows mediating the environment under the condition of deprivation with verbal operants.	100% accuracy using full sentences	100% accuracy using full sentences	100% accuracy using full sentences
Independent Tact (IT)	IT allows recruiting adult social attention under non-verbal stimulus control with verbal operants.	100% accuracy using full sentences	100% accuracy using full sentences	100% accuracy using full sentences
Intraverbal	Intraverbal enables verbally responding to questions in academic and social interactions.	80% accuracy using full sentences	80% accuracy using full sentences	70% accuracy using full sentences
Autoclitics	Autoclitics enables one to describe, qualify, quantify, manipulate, and relate to tacts and mands without direct instruction.	100% accuracy using 1 autoclitic	100% accuracy using 1 autoclitic	100% accuracy using 1 autoclitic

Note. Verbal behavior development includes four stages: pre-verbal, listener, speaker, and joining of listener and speaker (Greer et al., 2017). The level of verbal behavior for all participants is listener and speaker.

Table 2

List of sight words used in the experiment

Number	Set 1	Set 2	Set 3
1	am	egg	my
2	eat	more	all
3	find	no	this
4	they	time	now
5	us	are	to
6	toy	first	get
7	go	one	of
8	box	use	big
9	on	book	part
10	pig	if	sit
11	said	were	what
12	when	she	car

Note. The words were selected randomly from Think Tank Sight Words Flash Cards (Pre-K).

Table 3

The assignment of the sets of sight words to conditions of set-size-three, -six, and -twelve for each participant

Conditions	Indie	Kevin	Nathan
Set-size-three	Set 1	Set 3	Set 2
Set-size-six	Set 2	Set 1	Set 3
Set-size-twelve	Set 3	Set 2	Set 1

Note. Set-size-three represents the condition with 3 target words per session, set-size-six represents 6 target words per session, and set-size-twelve represents 12 target words per session.

Figure 1

General procedure of learn unit (LU) instruction

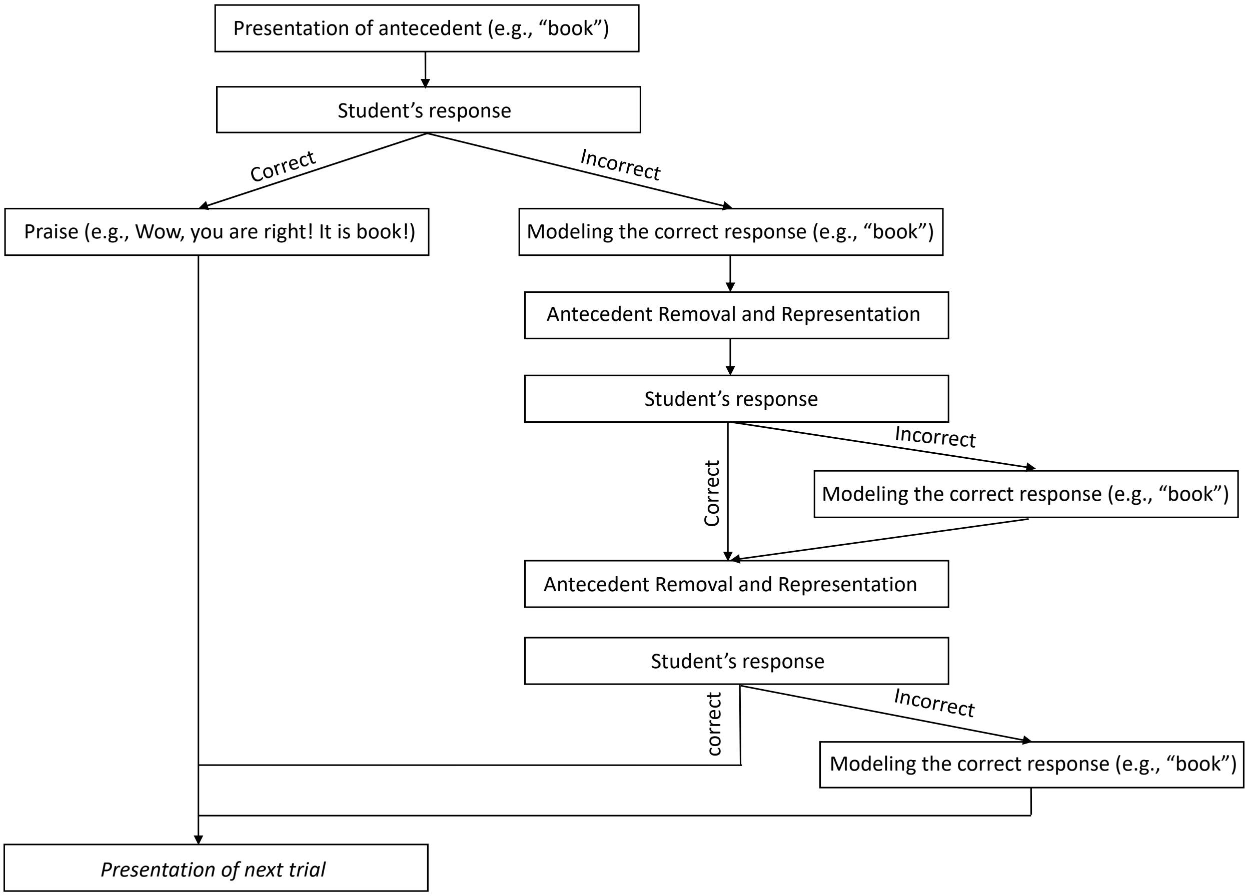
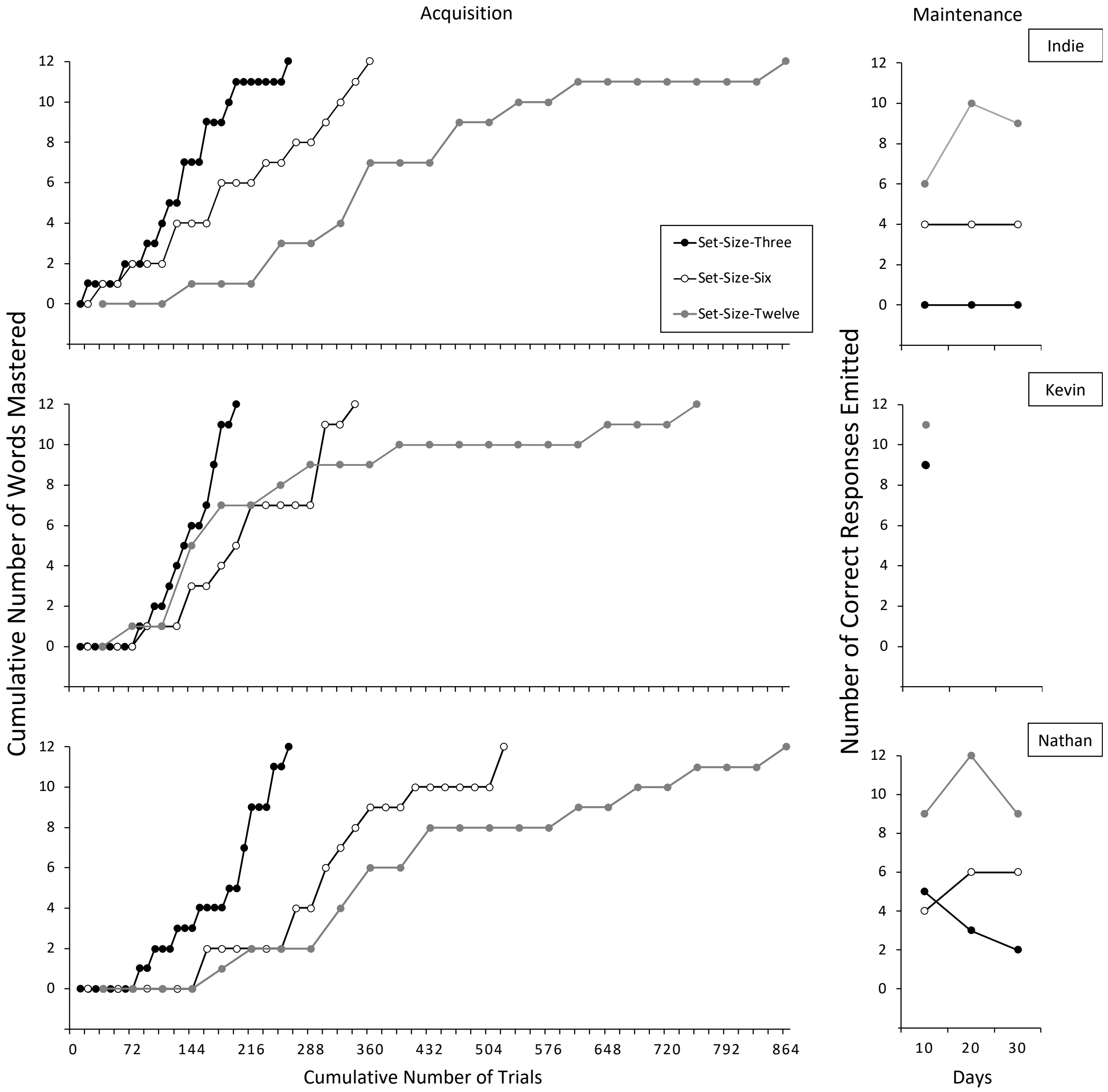


Figure 2

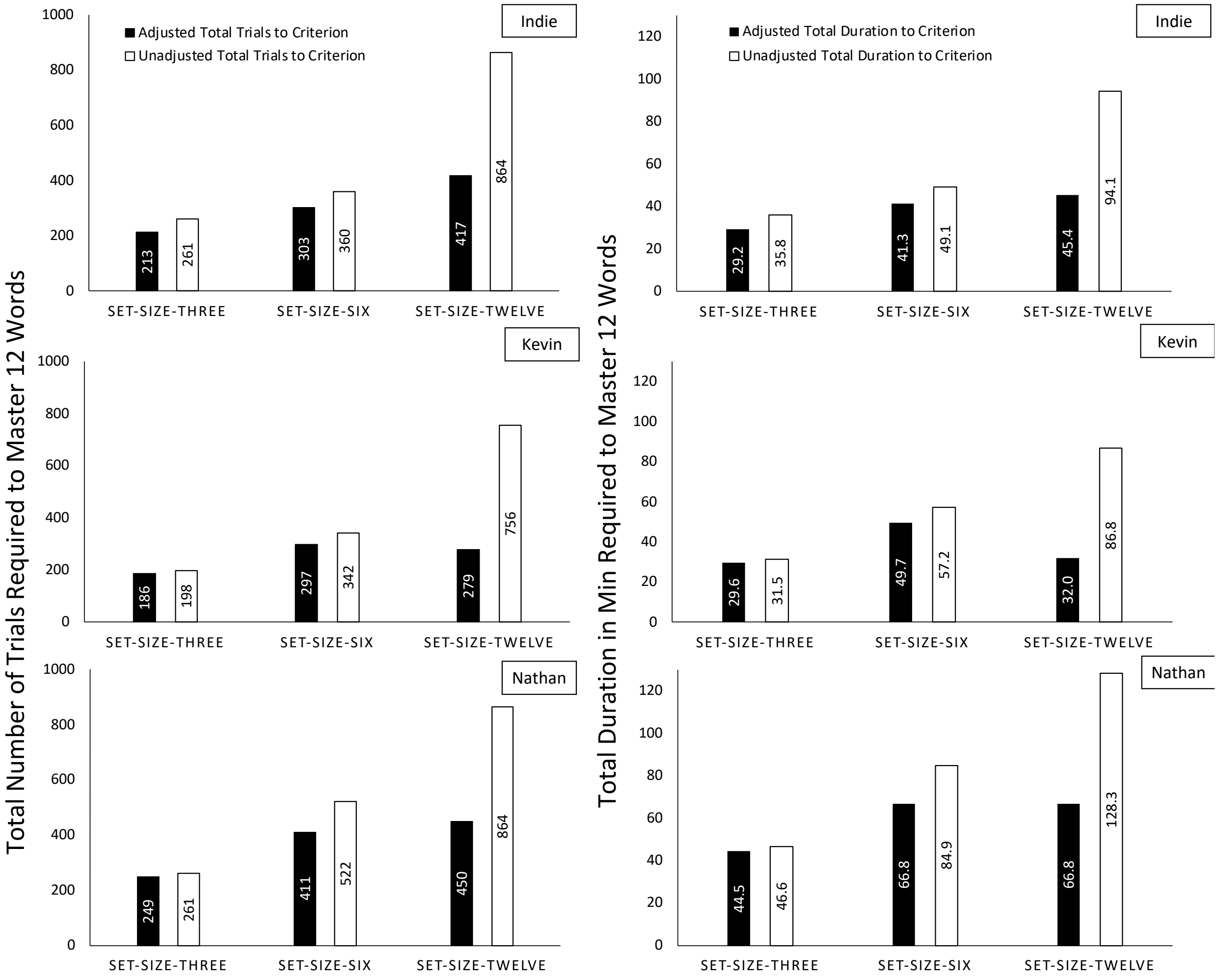
Cumulative sight words mastered during the baseline, acquisition, and maintenance for all participants



Note. Each interval on the *x*-axis represents 9 trials. Each dot represents the cumulative number of words masterd per number of trials delivered.

Figure 3

Adjusted and unadjusted total numbers of trials and total durations required to meet the acquisition criterion



Note. The adjusted total number of trials was calculated by excluding the trials delivered to the words that were mastered in the previous sessions. The adjusted total duration was calculated by dividing the adjusted total number of trials by the unadjusted total and multiplying by the unadjusted total duration.

Chapter 5

General Discussion

This research consisted of three experiments that investigated the stimulus control strengths of antecedents and contingent consequences in learning based on three-term contingencies. In the first experiment, we analyzed the stimulus control strengths in skill acquisition from preferred antecedent visual targets and contingent prosthetic reinforcers delivered by instructors. This study was the first study that directly compared the reinforcement strengths of the see-say correspondence of the preferred antecedent stimuli with the prosthetic reinforcers based on learn unit (LU) instruction. The results showed that all participants learned tacts faster for the preferred-visual-antecedent stimuli (PA; electronic devices) than the non-preferred-visual-antecedent stimuli (NA; vegetables) regardless of contingent consequences of praise-for-correct-response (PC) and math-for-correct-response (MC). The findings suggested that the strength of stimulus control from the see-say correspondence of preferred antecedent visual targets may be higher than from the prosthetic reinforcers delivered by instructors in skill acquisition.

In the second experiment, we controlled the reinforcement from the see-say/do correspondence of the antecedent visual stimuli and compared the stimulus control strengths between the prosthetic reinforcer and correction procedure in the learning of listener responses. This study was the first study that directly analyzed the component effects of LU instruction that involved praise for correct responses and correction procedures for incorrect responses. The results showed that the instruction procedure involving only correction procedures to incorrect responses (CI condition) and the procedure both prosthetic reinforcers to correct responses and correction procedures to incorrect responses (LU condition) were both effective on teaching listener responses and were more effective than the procedure involving only prosthetic reinforcers to correct responses (PC condition). Furthermore, LU instruction was not necessarily more efficient than the CI condition on acquisition of listener responses. The results suggested that the stimulus control strength from the correction procedure may be higher than from the prosthetic reinforcer in LU instruction. The correction procedure was probably necessary and sufficient for skill acquisition and maintenance for typically developing children and children with developmental delays who function on the listener and speaker levels of verbal behavior and have independent mands and tacts.

In the third experiment, we controlled the reinforcement of the see-say correspondence of the antecedent visual stimuli and the reinforcement of the contingent consequences and investigated the stimulus control strength of stimulus set sizes in learning. We systematically replicated Kodak et al. (2020) and Vladescu et al. (2021)'s research with further experimental control on the number of presentations per stimulus in each session in skill acquisition with the implementation of operant analysis (OA) acquisition criterion (Wong et al., 2021; Wong & Fienup, 2022). The results showed that the small set size of three stimuli was more efficient than the middle (set-size-six) and large set sizes (set-size-twelve) in skill acquisition, which were more consistent with Vladescu et al.'s findings, but not consistent with Kodak et al.'s findings. Furthermore, in contrast to Kodak et al.'s results that there were no differences on the number of independent correct responses across different set sizes at two weeks following the mastery, our results showed that the set-size-twelve condition reliably produced the best maintenance levels followed by the set-size-six and -three for all participants at 30 days following mastery. The opposing acquisition and maintenance results for small (e.g., three stimuli) and large (e.g., 12 stimuli) set sizes indicated that the stimulus control strength of the small stimulus set size may be higher than the large set size in skill acquisition, whereas the stimulus control strength of the latter higher than the former in skill maintenance.

5.1 Major Findings

A series of behavioral analytic studies have demonstrated that non-preferred antecedent visual stimuli, including academic stimuli (e.g., pictures, books, and math worksheets), could be established as conditioned reinforcers for students with and without disabilities (Buttigieg & Greer, 2021; Gentilini & Greer, 2020, 2021; Greer & Han, 2015; Maurilus, 2018; Lee, 2016; O’Rourke, 2006; Singer-Dudek et al., 2011; Tsai & Greer, 2006). Following the establishment of academic stimuli as conditioned reinforcers, students could either learn at an enhanced rate or learn in new ways (Buttigieg & Greer, 2021; Gentilini & Greer, 2020, 2021; Maurilus, 2018; Lee, 2016; O’Rourke, 2006; Tsai & Greer, 2006). When the temporal context regarding the access to the primary reinforcer is controlled, choice matches the rates of observing stimuli produced (Fantino, 2008). Thus, the choice outcomes in the preference assessment of the first experiment matches the preferences of the observing responses to the two sets of educational stimuli. The higher preference to observing the pictures of electronic devices than vegetables were affected by the participant’s respective reinforcement history. Since observing responses are operants (Holland, 1985), the results of the first experiment extended past findings that the see-say correspondence of the preferred visual stimulus may establish instant reinforcement that facilitates the acquisition of novel skills.

The outcomes of the first experiment also extended previous findings on the effects of the establishment of derived relations such as Incidental Bi-directional Naming (Inc-BiN) on the students' rate of learning. A variety of studies have identified that several interventions (e.g., multiple exemplar instruction, intensive tac instruction, and repeated probe procedures) involving repeated and prolonged exposures to the visual stimuli could reliably induce the capability of Inc-BiN and in turn facilitate the learning rates for children with disabilities (Fiorile & Greer, 2007; Greer et al., 2005; Hawkins et al., 2009; Hotchkiss & Fienup, 2020; Pistoljevic & Greer, 2006; Schmelzkopf et al., 2017). Considering that all participants learned faster for the preferred visual targets (i.e., MC-PA and PC-PA) than the non-preferred visual targets (i.e., MC-NA and PC-NA) regardless of the contingent consequences, we further suggest that the strength of the instant reinforcement from the see-say correspondence of preferred visual stimuli may be higher than the contingent consequence of prosthetic reinforcers in skill acquisition. The high strength of the instant reinforcement from the see-say/do correspondence of preferred visual antecedent stimuli might be the reason why students learned faster after the establishment of Inc-BiN.

According to the hypothetical framework regarding the stimulus control strengths proposed in Chapter I, the initial state of the organism (O), including the organism's physiological/dispositional/motivation state, affects the initial MOs related to the function of stimulus control over the target response. Based on this model, the results in the first experiment were consistent with the findings from neuroscience that the brain areas related to rewards and learning (e.g., the frontopolar cortex and intraparietal sulcus) were significantly more active during exploration (e.g., acquiring information on novel images) (Daw et al., 2006; Kidd & Hayden, 2015; Heilbronner & Platt, 2013; Pearson et al., 2011; Wittmann et al., 2008).

The second experiment identified the critical nature of corrections in the learning process. A variety of research focusing on skill acquisition from behavioral analytic perspective identified that contingent positive reinforcement for correct responses and correction procedures contingent on incorrect responses influenced the efficiency of skill acquisition for children with autism and developmental delays (Albers & Greer, 1991; Boudreau et al., 2015; Carroll et al., 2015, 2018; Ingham & Greer, 1992; Johnson et al., 2017; Karsten & Carr, 2009; Vladescu & Kodak, 2010). Nevertheless, these studies usually involved the implementation of differential reinforcement with correction procedures (Carroll et al., 2015, 2018; Joachim & Carroll, 2018; Kodak et al., 2016; McGhan & Lerman, 2013). The second experiment isolated and compared the effects of corrections for incorrect responses and reinforcement for correct responses in skill acquisition and identified that the correction procedure might be the reason why children learned faster when the instruction involved both correction procedures and differential reinforcement. The results were consistent with the findings of studies focusing on peer tutoring and observational learning. The researchers (Greer et al., 2004; Neu & Greer, 2019) found that elementary school students with and without developmental delays acquired novel skills (e.g., Korean terms and math problems) faster from observing their peers only receiving contingent corrections to incorrect responses during LU instruction as compared to observing peers only receiving positive reinforcement following correct responses. The results of the second experiment extended previous findings that the correction procedure may be a necessary component in skill acquisition for typically developing children and high functioning children with developmental delays who function on the listener and speaker levels of verbal behavior and have independent mands and tacts.

The outcomes of the second experiment also extended past research findings on the possible sources of stimulus control in correction procedures. The effects of correction procedure on increasing correct responses are commonly viewed as a result of negative reinforcement, such that additional prompted responses are required following the student's emission of an incorrect response before the trial is terminated (Cariveau et al., 2019; Rodgers & Iwata, 1991). However, considering the consistent and overall faster acquisition and higher maintenance level in the CI condition, in which contingent corrections were delivered following incorrect responses and no reinforcers following correct responses (as compared to the LU condition), we suggest other sources of stimulus control in addition to negative reinforcement in the correction procedure. Specifically, the modeling of the correct response immediately following an error in the correction procedure might serve a critical function in promoting the transfer of stimulus control in skill acquisition. According to Fantino (2010), "useful" or positive information could function as conditioned reinforcers and maintain the observing responses. When the antecedent stimulus is a preferred stimulus for observing, the modeling of the correct response in the correction procedure may provide "positive" information to maintain the observing response and enhance the strength of stimulus control. This hypothesis is consistent with the findings from neuroscience that when the choice did not result in immediate reinforcement between gambles with identical probabilities (50/50) and payoffs (i.e., juice), monkeys reliably chose the option with the immediate feedback regarding winning or losing the game, even when it was accompanied with cost (Blanchard et al., 2015; Bromberg-Martin & Hikosaka, 2009, 2011).

Furthermore, Gruber et al. (2014) found that dopamine neurons signaled both direct rewards and information, suggesting that information also functioned as rewards in the learning process. In the first experiment, 3 out of 3 participants successfully mastered the preferred visual targets in the MC-PA condition, whereas 2 out of 3 participants mastered the non-preferred stimuli in the MC-NA condition. In the second experiment, the CI procedure was sufficient for 3 out of 6 participants with educational stimuli and 5 out of 6 participants with abstract stimuli. Based on the results of the first and second experiments, we suggest that the correction procedure may be sufficient in learning preferred visual stimuli for children similar to those who participated in this research.

Lastly, the results of the third experiment demonstrated that the set size of the antecedent stimuli also affected the initial MOs level and the strength of antecedent stimulus control in skill acquisition. The curricular manuals on skill acquisition for children with disabilities recommended including at least three stimuli in a stimulus set in the learning of listener and speaker responses (Greer & Ross, 2008; Greer et a., 2020; Grow & LeBlanc, 2013; LaMarca & LaMarca, 2018; MacDonald & Langer, 2018). The results of the third experiment extended past findings that the small set size (three stimuli) was more efficient than the bigger stimulus set sizes (six and twelve stimuli) on skill acquisition. Furthermore, we identified opposite effects between the small and large stimulus set sizes on acquiring and maintaining the speaker responses. The opposing outcomes question whether efficiency of initial acquisition should be the comparison researchers make (Wolery et al., 1991). A core goal of ABA is to produce durable behavior change (Baer et al., 1968) and the data reported in this experiment demonstrated that effectiveness and efficiency during acquisition phases do not correlate with the durability of responding (maintenance assessments). Controlling for the instant reinforcement of antecedent visual stimuli and the reinforcement of contingent consequences, the stimulus control strength of small set size was stronger than the larger stimulus set sizes in skill acquisition, whereas the large stimulus set size may contribute more to the stimulus control strength in skill maintenance. Thus, we suggest the skill acquisition rates as measures of efficiency for an instruction procedure, whereas the skill maintenance levels - how well and how long a student can maintain an acquired skill - as measures of effectiveness.

5.2 Implications

The outcomes of current research suggest several areas on the analysis of antecedent and consequence stimulus control in learning for future research. First, since we involved only one set of preferred visual antecedent stimuli and one non-preferred stimuli for all participants in the first experiment, future research may replicate the procedure and investigate the antecedent stimulus control strengths in skill acquisition with different preferred and non-preferred stimulus sets and multiple instruction programs requiring different responding topographies. As discussed before, the findings in the first and second experiments may suggest a synergistic result of positive and negative reinforcement in the correction procedure for learning preferred visual stimuli. Thus, future research may further test such hypotheses by conducting component analyses examining the effects of the correction procedures on skill acquisition with preferred and non-preferred visual stimuli. Since previous and current studies focused on the effects of stimulus set sizes for speaker responses (e.g., tact), the generality of the results of the third experiment to multiple instruction programs requiring different responding topographies (e.g., listener responses) needed further verification. Additionally, considering the opposite results between the skill acquisition and maintenance for small and large stimulus set sizes, we suggest future research investigate the effects of different set sizes on skill acquisition and maintenance with further control on overlearning trials and discuss the definition of effectiveness and efficiency in learning novel skills (Wolery et al., 1991). Additionally, all participants in this research were high functioning with regard to language development (e.g., follow multiple step instructions; emit independent mands and tacts using full sentences) and self-management skills (e.g., sit at the table appropriately for 5 min). The generality of the results to children with lower levels of compliance, less robust verbal repertoires, and different instructional histories needed further verification. Lastly, we used praise as prosthetic reinforcers throughout the research. Future research may replicate the results of all experiments using other prosthetic reinforcers (e.g., tokens and edibles). Although praise functioned as conditioned reinforcers for all the participants in the study, the delivery of highly preferred items following the independent correct responses might affect the strength of stimulus control in skill acquisition. The results with other prosthetic reinforcers would help verify the findings regarding the stimulus control strengths in learning of preferred visual antecedent stimuli, correction procedures, and stimulus set sizes. Despite the need of future research to further clarify aforementioned concerns, the findings in this research identified the contributions of preferred visual antecedent stimuli, prosthetic reinforcers, correction procedures, and stimulus set sizes to the stimulus control in learning, which provide valuable information for instructors to enhance the arrangement of instruction procedures (e.g., conditioning non-preferred visual stimuli as reinforcers) and in turn effectively improve the students' academic achievement in varied educational settings. The results of these studies were consistent with the framework proposed in Chapter I that the strength of stimulus control was a function of the synergistic reinforcement strengths across multiple correspondences of MOs, S^Ds, the target response, and the corresponding reinforcers.

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