Using equivalence-based instruction to teach the visual analysis of graphs

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Previous research has demonstrated low rater agreement when visually inspecting trends in single-subject design graphs (see Wolfe, Seaman, & Drasgow, 2016). Didactic instruction of visual analysis of practicing behavior analysts has resulted in generally poor and unreliable performances (Danov & Symons, 2008; Diller, Barry, & Gelino, 2016). Therefore, a refined instructional technology to improve the reliability among behavior analysts is warranted. Developing research has focused on the application of equivalence-based instruction (Brodsky & Fienup, 2018; Rehfeldt, 2011) for a variety of complex human behaviors. In the current study, equivalence-based instruction was used to train four participants to identify functional relations displayed in five different classes of graphs. Training resulted in the formation of five equivalence classes by all participants consisting of three members (graph, functional relation rule, and functional relation statement). In addition, the skills were maintained for up to 2 weeks and generalized to novel graphs.

KEYWORDS
match-to-sample, multiple-exemplar training, stimulus equivalence, visual analysis
INTRODUCTION

One of the fundamental qualities of behavior analysis is its use of visual analysis of data. Unlike other fields (e.g., psychology) that rely on statistical comparisons and the standardization of collected data, behavior analysts rely almost exclusively on the visual inspection of summarized and plotted data over time. An extensive line of research has suggested that teaching visual analysis of graphs using standard didactic approaches and traditional supervisory methods might not lead to the development of fluent and reliable visual analytic repertoires in practicing behavior analysts (Danov & Symons, 2008; DeProspero & Cohen, 1979; Diller et al., 2016; Ninci, Vannest, Willson, & Zhang, 2015; Ottenbacher, 1993; Wolfe et al., 2016). However, a few studies have shown that when participants are directly taught specific visual analysis rules, agreement across participants improved (Hagopian et al., 1997; Roane, Fisher, Kelley, Mevers, & Bouxsein, 2013).

The essential skill for behavior analysts, specifically, is to identify whether graphically presented data demonstrate a functional relation between the independent and dependent variables. This skill is necessary to determine whether interventions are effective, and in some cases, to identify the specific components of interventions that are controlling the target behavior(s). However, few studies have investigated different instructional methods for teaching students and practitioners to reliably visually analyze graphs to determine functional relations between independent and dependent variables in more common behavior analytic experimental designs (Wolfe et al., 2016).

One promising instructional framework that focuses on the direct teaching of a few specific skills and the emergence of novel responding is the application of derived stimulus relations methodologies (Hayes, Barnes-Holmes, & Roche, 2001) in general, of which stimulus equivalence (Sidman, 1994) appears to be an example. In several studies, participants were exposed to direct teaching methods with multiple exemplars, resulting in the emergence of relational responding across an array of stimulus parameters, participants, training settings, and instructional protocols (Hayes et al., 2001; Sidman, 1994).

When stimuli that share no topographical similarities become part of the same class of stimuli, an equivalence class has formed (Green & Saunders, 1998; Sidman, 1994; Sidman & Tailby, 1982). In order to demonstrate that an equivalence class has emerged, the properties of reflexivity (A = A), symmetry (if A = B then B = A), and transitivity (if A = B and B = C then A = C) must be demonstrated among the stimuli that form the class. For an equivalence class to form, a learner must consistently select a member of an equivalence class when presented with other members of the same class. Conditional discrimination training, specifically match-to-sample (MTS) training, is a common method of establishing equivalence classes. There have been a number of published studies on the establishment of stimulus equivalence (see Sidman, 1994; Stromer, Mackay, & Stoddard, 1992, for thorough reviews). Additionally, a growing number of investigations have been conducted using equivalence-based instruction (EBI) to teach standard college-level content to typically developing adults (Brodsky & Fienup, 2018; Rehfeldt, 2011).

In a series of studies (Critchfield & Fienup, 2010; Fields et al., 2009; Fienup, Covey, & Critchfield, 2010; Fienup & Critchfield, 2010), EBI was used to teach college student complex skills such as those required for interpreting statistics, and for relating facts about brain anatomy. The studies used computer-based training to teach and test the relations involved in the equivalence classes. In all studies, derived relational responses emerged and generalized to novel exemplars. In another study that used EBI procedures, Walker and Rehfeldt (2012) taught graduate students in a distance-learning program to identify single-subject design graphs via a computer-based system. Participants learned to select the definitions of research designs and graphs when presented with the names, and to select vignettes when presented with definitions of designs. After training, participants demonstrated several emergent selection-based and topographical responses including selecting and writing the names of designs when presented with graphs and vignettes, and selecting the definitions of designs when presented with vignettes. The results of the study suggested that with direct training of specific discriminative responses, derived relational responses emerged. The authors concluded that EBI was an efficient method for teaching higher-level concepts to college students with minimal instruction (Walker & Rehfeldt, 2012). However, one limitation noted was that the training did not result in acceptable generalization to novel stimuli for all participants.
Two studies that used EBI to teach academic skills were recently published (Albright, Reeve, Reeve, & Kisamore, 2015; Albright, Schnell, Reeve, & Sidener, 2016). In both studies, the investigators used EBI to teach complex skills such as the concepts of statistical variability and the interpretation of the results of functional analysis graphs to college students. Custom computer software delivered MTS trials in the experimental sessions in a pretest-train-posttest-maintenance design. They incorporated multiple-exemplar training (MET) in order to promote generalization. In the first study, participants learned to select statistical category definitions, sample numbers, and standard deviation definitions when presented with category names. In the second study, participants learned to select graph descriptions and graphs when presented with the function and to select a vignette when presented with a graph description. Both studies resulted in substantial increases in scores from pretest to posttest conditions and equivalence classes formed for all participants. Results also suggested that skills were maintained at 1 week, and generalized to novel stimuli. 

The purpose of the current study was to systematically replicate and extend studies on EBI (e.g., Albright et al., 2016; Walker & Rehfeldt, 2012) with an eminently applied skill for behavior analysts. In recent studies, EBI has been shown to be effective in teaching relevant academic skills to college students and the current study further extends this line of research. The specific purpose of the current study was to investigate whether a visual–visual MTS procedure with MET, in which conditional discriminations between graphs and analytic rules, and between analytic rules and functional relation statements, were taught, resulted in the formation of equivalence classes based on the level of functional relation, including the emergence of derived relational responding in the form of selecting a functional relation statement when presented with an ABAB design graph.

2 | METHOD

2.1 | Participants

Two undergraduate students and two direct care staff who worked at an agency that provides services to children diagnosed with autism spectrum disorder, participated in the study. We recruited participants via direct email, posts on an online course site, and posts on social media. The four participants (one man and three women) ranged in age from 19-to 25-years-old. A screening tool was used to determine the participants’ level of experience with, and exposure to, the visual analysis of graphs. No participants had any experience with studying or implementing single-subject designs. The Endicott College Institutional Review Board approved this research project. Prior to participation, all participants signed a consent form and they received a gift card for participating in the study, regardless of whether the participant completed all parts of the training and testing.

2.2 | Setting and materials

Experimental sessions were conducted in a small student lounge or a conference room with desktop or laptop computers. For all sessions, we used the same custom web-based software that Albright et al. (2016) developed specifically for use in EBI research to design the EBI system and to deliver and control the MTS training and testing sessions (the software is not commercially available). The developers of the EBI training software designed the system to automatically present visual–visual MTS training and testing trials and conditions to the participant via a web browser based on the mastery criteria and in the order that was programmed by the researcher. In addition, the software recorded participants’ responses as data in spreadsheet table form.

2.3 | Experimental stimuli, training protocol, and training structure

The visual stimuli (see Table 1 and Figure 1) used were graphs (denoted as A), written visual analysis rule statements (denoted as B), and written functional relation statements (denoted as C), displayed on a computer screen. Five
<table>
<thead>
<tr>
<th>Label</th>
<th>Class</th>
<th>Notation 1</th>
<th>Notation 2</th>
<th>Notation 3</th>
<th>Notation 4</th>
<th>Notation 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Graph</td>
<td>A_x</td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
<td><img src="image5.png" alt="Image" /></td>
</tr>
<tr>
<td></td>
<td>A_y</td>
<td><img src="image6.png" alt="Image" /></td>
<td><img src="image7.png" alt="Image" /></td>
<td><img src="image8.png" alt="Image" /></td>
<td><img src="image9.png" alt="Image" /></td>
<td><img src="image10.png" alt="Image" /></td>
</tr>
<tr>
<td></td>
<td>A_z</td>
<td><img src="image11.png" alt="Image" /></td>
<td><img src="image12.png" alt="Image" /></td>
<td><img src="image13.png" alt="Image" /></td>
<td><img src="image14.png" alt="Image" /></td>
<td><img src="image15.png" alt="Image" /></td>
</tr>
<tr>
<td>Rule</td>
<td>B</td>
<td>There is a clear change in level and trend between baseline and treatment conditions</td>
<td>There is a change in level between baseline and treatment conditions and the trend is variable across conditions</td>
<td>The trends in all conditions are too variable to make a determination of whether there is a functional relation</td>
<td>There is a slight change in level between baseline and treatment conditions and the trend is variable across conditions</td>
<td>There is no change in level or trend between baseline and treatment conditions</td>
</tr>
</tbody>
</table>
equivalence classes (1. Functional Relation, 2. Probable Functional Relation, 3. Unclear, 4. Probably No Functional Relation, and 5. No Functional Relation) were established. The graphs were 30 ABAB figures with varying behaviors, levels, trends, and numbers of data points per condition and were created for this study and did not represent actual clinical or research data. Fifteen graphs were used during training, and 15 novel exemplars were used for the generalization probes. We chose ABAB because, “they are the most straightforward and powerful within-subject design for demonstrating functional relations between environmental manipulations and a behavior” (Cooper, Heron, & Heward, 2007, p. 177). To program for generalization, we included three exemplars of each graph (denoted as \(A_x, A_y, A_z\)) for each equivalence class. Prior to the study, three PhD level BCBA-Ds reliably identified the graphs by class. For the functional relation rule (B) and functional relation statement (C) stimuli, one stimulus was included in each class. During all sessions, all stimuli were presented as black-and-white images on a computer screen. The size of the stimuli that the software displayed depended on the computer monitor size and resolution; however, for this study, all stimuli were approximately 7.5 cm × 7.5 cm.

We used a simple-to-complex training protocol and linear training structure (Table 2 and Figure 2) for this experiment (Arntzen, 2012; Saunders & Green, 1999). We designed the system to teach the AB baseline discriminations, then present the BA symmetry test, then teach the BC baseline discriminations, then present the CB symmetry test. Finally, the system presented the AC transitivity test followed by the CA equivalence test. The system automatically presented training and testing conditions based on the programmed mastery criteria for each condition.

2.4 | Experimental design and dependent variables

We used a single-session pretest-posttest design, embedded in a two-tier nonconcurrent multiple baseline across participants design (Carr, 2005; Christ, Cooper, Heron, & Heward, 2007; Watson & Workman, 1981) to examine experimental control and assess the effects of conditional discrimination training in the form of MTS on the formation of five three-member classes. We exposed Participants 2 and 4 to two pretests, conducted in two successive conditions in a single session, to control for testing effects (Griffith, Ramos, Hill, & Miguel, 2018). Finally, we conducted maintenance and generalization probes for all participants. The primary dependent variable was the percentage of correct trials for all relations, particularly transitivity and equivalence relations, during testing conditions. We also calculated the trials-to-criterion for all participants for AB and BC training conditions, and training and testing durations.
TABLE 2  Training and testing sequence and parameters

<table>
<thead>
<tr>
<th>Condition</th>
<th>Relations trained or tested</th>
<th>Trials per block</th>
<th>Mastery criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interface</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Pretest</td>
<td>AB, BA, AC, CA, BC, CB</td>
<td>60</td>
<td>N/A</td>
</tr>
<tr>
<td>AB Train</td>
<td>AB</td>
<td>15</td>
<td>15/15 in one block</td>
</tr>
<tr>
<td>BA Test</td>
<td>BA</td>
<td>15</td>
<td>14/15 in one block</td>
</tr>
<tr>
<td>BC Train</td>
<td>BC</td>
<td>5</td>
<td>5/5 in one block</td>
</tr>
<tr>
<td>CB Test</td>
<td>CB</td>
<td>5</td>
<td>5/5 in one block</td>
</tr>
<tr>
<td>AC Test</td>
<td>AC</td>
<td>15</td>
<td>14/15 in one block</td>
</tr>
<tr>
<td>CA Test</td>
<td>CA</td>
<td>15</td>
<td>14/15 in one block</td>
</tr>
<tr>
<td>Posttest</td>
<td>AB, BA, AC, CA, BC, CB</td>
<td>60</td>
<td>N/A</td>
</tr>
<tr>
<td>Generalization</td>
<td>AC</td>
<td>15</td>
<td>N/A</td>
</tr>
<tr>
<td>Maintenance</td>
<td>AB, BA, AC, CA, BC, CB</td>
<td>60</td>
<td>N/A</td>
</tr>
</tbody>
</table>

FIGURE 2  Training protocol (simple-to-complex) and structure (linear)

2.5  Procedural integrity and interobserver agreement

The researcher used a written checklist to ensure that the correct conditions were conducted with the correct participants and the researcher read instructions to ensure that all participants were provided with the appropriate
instructions for each condition. Primary and secondary observers assessed procedural integrity via recorded video in 33% of experimental sessions. According to the primary observer, the researcher completed 100% of the steps correctly. We calculated interobserver agreement for procedural integrity by dividing the total number of steps with observer agreement by the total number of possible steps and multiplying by 100. Interobserver agreement was 100%.

2.6 | Procedure

2.6.1 | Visual analysis social validity

Prior to the start of the study, 12 Master’s level Board Certified Behavior Analysts® (BCBAs) enrolled in a PhD program in ABA were asked to assess the level of functional relation for 30 ABAB graphs.

2.6.2 | Visual–visual MTS training and testing system

Prior to the start of a block of trials the system presented the following instructions to participants, “Select the stimulus that matches the sample stimulus. During this block you will be immediately notified if your selection was correct or incorrect” or, “During this block you will not be notified if your selection was correct or incorrect.” After clicking “OK,” the system presented the first trial.

A trial consisted of the presentation of a visual sample stimulus at the top of the computer screen, the display of the total number of trials in the training/testing block, the number of trials remaining, and a progress indicator. When the participant clicked the sample stimulus (e.g., A1) with a computer mouse, the system presented five visual comparison stimuli on the screen (one correct member (e.g., B1) of the class and four incorrect members, one from each of the other classes (e.g., B2, B3, B4, and B5) in an array (randomly located) at the bottom of the screen. Trial-and-error instruction was used for the MTS training conditions. During training trials, clicking on the comparison stimulus resulted in immediate feedback (“Correct” or “Incorrect”). If a participant selected the correct stimulus, it was identified as correct, and when the participant clicked anywhere on the screen the system presented the next trial; however, if a participant selected an incorrect stimulus, the correct stimulus was not identified and the next trial was presented. During testing trials, clicking on any comparison stimulus resulted in no feedback and the next trial was immediately presented. Prior to the start of sessions, participants completed a simple computer-based visual–visual MTS task (color name-to-color) in order to familiarize themselves with the computer software and matching task. All participants responded correctly for all interface training trials.

2.6.3 | Pretest

Immediately following the interface training, the researcher initiated the pretest condition. The pretest condition randomly presented all possible conditional discriminations and exemplars (graph-to-functional relation rule [AB], functional relation rule-to-functional relation statement [BC], functional relation rule-to-graph [BA], functional relation statement-to-functional relation rule [CB], graph-to-functional relation statement [AC], and functional relation statement-to-graph [CA]) as individual trials one time in a single block of trials. At the end of the pretest, the researcher immediately started the MTS training and testing session.

2.6.4 | MTS training and symmetry tests

During the baseline training conditions (AB and BC), the system trained participants to select the correct comparison stimulus from an array when presented with a sample stimulus. Trials were presented in blocks until participants met the mastery criterion (100% correct for one block). Immediately following a successful baseline training condition, the
system automatically presented participants with the corresponding symmetry (BA or CB) test. If a participant failed a symmetry test, the corresponding baseline relation training condition was presented again.

2.6.5 | Transitivity and equivalence probes

Immediately following successful symmetry tests, the system presented participants with transitivity (AC) and equivalence (CA) probes. If a participant failed either these tests, the AB training condition was presented again and the participant proceeded through the training and testing system until mastery criteria for all conditions were met (Figure 2).

2.6.6 | Posttest

Immediately following a successful equivalence (CA) test, the researcher initiated the posttest. The posttest condition was identical to the pretest condition.

2.6.7 | Generalization

We initially conducted generalization probes with BAB reversal graphs with Participants 1 and 3 immediately following the posttest (data not shown). However, due to a lower than expected performance for Participant 3, we also conducted generalization probes with ABAB reversal graphs with all four participants. Due to this change in method during the study, we conducted generalization probes after maintenance probes for Participants 1 and 3 and prior to maintenance probes for Participants 2 and 4. Probes were identical to the AC test condition except with novel graphs.

2.6.8 | Maintenance

All participants completed maintenance probes an average of 15 days (range, 14 to 17) after the training sessions. The maintenance test was identical to the pretest and posttest conditions.

2.6.9 | Satisfaction survey

At the conclusion of the study, all participants voluntarily completed a satisfaction survey (see Table 3).

<table>
<thead>
<tr>
<th>Question</th>
<th>Mean</th>
<th>Range (1–5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prior to this training, how confident were you in your ability to visually analyze graphs?</td>
<td>1.5</td>
<td>1–2</td>
</tr>
<tr>
<td>After this training, how confident are you in your ability to visually analyze graphs?</td>
<td>3.5</td>
<td>3–4</td>
</tr>
<tr>
<td>The computer-based training helped me learn about visually analyzing graphs.</td>
<td>4.0</td>
<td>4–4</td>
</tr>
<tr>
<td>I felt successful during the training and testing.</td>
<td>4.0</td>
<td>3–5</td>
</tr>
<tr>
<td>Compared to other instructional methods (e.g., lecture, reading a textbook, and study guide questions), rate your preference for this type of instruction.</td>
<td>2.8</td>
<td>2–4</td>
</tr>
<tr>
<td>The computer-based training frustrated me.</td>
<td>3.3</td>
<td>2–4</td>
</tr>
<tr>
<td>I would use this type of instruction to learn other concepts and to help me master other material.</td>
<td>3.3</td>
<td>3–4</td>
</tr>
<tr>
<td>I would recommend this type of instruction to others.</td>
<td>3.3</td>
<td>2–4</td>
</tr>
</tbody>
</table>
3 | RESULTS

The mean score for the visual analysis social validity test that was completed by 12 Master’s level BCBAs enrolled in a PhD program in ABA was 73% (range, 60% to 90%). Participant scores for the pretests were below 60% (range, 35% to 57%) for all four participants (see Figures 3 and 4). Both Participants 2 and 4 showed slight increases in overall scores from pretest 1 to pretest 2; however, the performance for CA relations for Participant 2 decreased. Immediately after completing the training conditions, Participants 1, 3, and 4 passed symmetry (BA, CB), transitivity (AC), and equivalence (CA) tests, whereas Participant 2 failed symmetry and transitivity tests and required remedial training to meet the mastery criteria. The mean total number of trials (Table 4) to complete training and testing was 234 (range, 150 to 440). The mean duration of MTS training and emergent relation testing sessions was 49 min (range, 13 min to 2 hr 16 min). The posttest scores for all relations and participants showed a substantial improvement in performance when compared to pretest scores, with little variability across participants. All participants scored 89% or higher on the posttest (range, 89% to 97%) for all relations.

There was some variation in participant responding during the ABAB generalization probes. The mean score for all participants was 80% (range, 73% to 87%). The maintenance scores for all relations and participants showed that trained and emergent relational responding maintained for 2 weeks for three out of four participants (the score for Participant 3 dropped to 77% during the maintenance probe).

Table 3 shows the results of the satisfaction survey that all participants completed at the end of the research. The results suggest that all participants were generally satisfied with and accepting of the training procedures.

4 | DISCUSSION

Research in the area of stimulus equivalence and derived relational responding (Hayes et al., 2001; Sidman, 1994) has focused on the acquisition of basic discriminative and emergent responses in structured settings. However, a recent
focus on using EBI with MET has yielded promising results with a wide range of learners and across an array of complex skills (Brodsky & Fienup, 2018; Rehfeldt, 2011). When compared to more traditional didactic teaching methods, this methodology of instruction appears to be an effective alternative, especially when the formation of equivalence classes, as opposed to simple stimulus generalization, is the goal of the instruction.

In the current study, we used a web-based EBI system to teach visual analysis of graphical data to undergraduate students and direct care staff who had no experience with the analysis of single-subject data graphs. For all participants, five three-member classes of arbitrarily related stimuli were formed using automated visual–visual MTS and MET training of baseline discriminations (AB and BC). In addition, the skills maintained for at least 2 weeks and were applied to several novel exemplars. All participants who completed the study learned the directly trained baseline discriminations, derived relational responding immediately emerged for three out of four participants, and all participants passed the tests for the emergence of symmetrical relations (BA, CB), and transitivity and equivalence relations (AC, CA) by the end of training and testing. These results replicate and extend recent studies (Albright et al., 2015; Albright et al., 2016; Fienup & Critchfield, 2010; Walker & Rehfeldt, 2012) where the current study

<table>
<thead>
<tr>
<th>Participant</th>
<th>Trials to mastery criterion</th>
<th>Remedial</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>105 15 5 5 15 15 N</td>
<td>13 min</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>270 45 60 20 30 15 Y</td>
<td>2 hr 16 min</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>135 15 10 5 15 15 N</td>
<td>23 min</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>90 15 10 5 15 15 N</td>
<td>26 min</td>
<td></td>
</tr>
</tbody>
</table>
better controlled for testing effects when compared to previous studies, and with novel complex stimuli that are socially relevant to behavior analysts.

The current study also replicated and extended the results from Walker and Rehfeldt (2012) by using EBI to teach participants to visually analyze data in single-subject research designs. However, where the researchers trained participants to identify and define single-subject research designs using a stimulus equivalence paradigm and MET, the current study extended the identification of research designs to the selection of functional relation statements related to ABAB graphs using a similar training procedure. In contrast to some previous studies, the data from the current study suggest that not only did equivalence classes form and participants learned to discriminate functional relations, but the skills also generalized to novel stimuli.

In the current study, 12 BCBAs enrolled in a PhD program correctly matched a graph to a functional relation statement in only 73% of opportunities. By comparison, the four participants who completed EBI training in the current study accurately selected a functional relation statement when presented with a graph in 93% (range, 85% to 100%) of opportunities immediately following training, and in 81% (range, 73% to 90%) of opportunities 2 weeks after training. Participants in the current study also accurately selected a functional relation statement when presented with a novel graph in 80% (range, 73% to 87%) of opportunities. In addition, three out of four participants required less than 30 min of training to demonstrate this ability, which is considerably less time than is usually required to teach this skill using more traditional methods. The results of the satisfaction survey add to previously published literature that showed that participants are generally receptive to this type of instruction and prefer it to other types of instruction (Albright et al., 2015; Albright et al., 2016). The results of the satisfaction survey for this study confirmed that participants had very little confidence in their ability to visually analyze graphs prior to the training and felt fairly confident in their skills after training.

The primary limitation of this study is the use of a pretest/posttest design where only two participants were exposed to multiple pretest probes. The design significantly limits the conclusions of the study, and future research should choose a stronger design. Another limitation to this study was the results for generalization. After training, one participant did not generalize the identification of functional relation statements to BAB graphs, which prompted us to include generalization probes with ABAB reversal graphs for all participants. When presented with novel ABAB graphs all four participants correctly identified the functional relation statement at relatively high percentages. Given the limited number of exemplars used in the current study, future studies should investigate how reliably the rule statements can be applied to a variety of graphs of different research design types or even actual clinical data. In addition, future research should test how the rules learned in this study apply to clinical decision-making behavior. Future research should also investigate the parameters of the exemplars used in training in order to ensure the generalization of responding to novel stimuli without the need for further training.

A third limitation of the study was the high number of training trials needed to meet training criteria and pass the emergent relations (AC, CA) tests for Participant 2. Compared to other studies on EBI (e.g., Albright et al., 2016), the results for this participant appear to be somewhat atypical. Given that the visual analysis of graphs is a complex, possibly rule-governed behavior that might include unobserved covert behavior (e.g., tacts and intraverbals), the slow acquisition might be due in part to the topography of the behavior itself. The slower acquisition of the trained conditional discriminations, and lack of immediate emergence of untrained responding, might have also been related to the inherent complexity of the compound stimuli (written phrases and graphs). Anecdotal reports from participants revealed that many had never seen single-subject graphs before and as a result struggled with the initial AB training blocks. However, after a participant "got it," the participant appeared to progress through the training more quickly, and the results of the study, particularly the immediate emergence of derived relations following training for three out of four participants, support these self-assessments. Future research should investigate prerequisite skills of participants, conditional discrimination training in EBI with complex/compound visual and written stimuli, fluency with the terms and possible technical jargon in the stimuli, and pre-training instructions given to participants.

A fourth limitation was that it is possible that participants were exposed to further instruction or self-initiated study in the area of visual analysis. However, given the somewhat arbitrary nature of the stimuli included in the
current study, the fact that participants were all full-time undergraduate students or worked full-time, and the fact that they likely did not have many opportunities to be exposed to the skill of visually analyzing graphs in the 2 weeks between posttest and maintenance, it appears unlikely that any other variables influenced the performance during maintenance.

A final limitation of the study was related to the skill itself that was taught. A functional relation is not a binary phenomenon—there are degrees to the amount of control that an independent variable has on a dependent variable, especially in nonlaboratory settings (e.g., classrooms, home, and community). However, the stimuli used in this study were admittedly somewhat arbitrarily created by behavior analysts according to simplified generally accepted rules. Future studies in the area of visual analysis should use systematic criteria and rules for classifying graphs (e.g., overlapping data points and slopes of trends) and not simply rely on interrater agreement for the establishment of categories of graphs.

For the current study, we probed for the maintenance of skills only once following training. Although the results of the study suggest that participants mastered the skills, equivalence classes formed, and responses maintained for several weeks for most participants, the long-term effects of a single training session of EBI are unknown. Future research should focus on the effects of EBI on long-term maintenance as well as the effects of shorter-duration refresher/remedial trainings on maintenance and generalization.

Future research should also investigate using EBI to teach other applied behavior analytic skills associated with clinical activities. For example, some applied skills might include selecting appropriate function-based treatment, assessment procedures, and data collection methods. The current study used EBI to teach the visual analysis of ABAB reversal graphs; however, future studies could investigate the efficacy of EBI for teaching visual analysis skills for other graphs, specifically multiple baseline graphs given their widespread use in ABA research.

The results of the current study confirm that typically developing adults can discriminate topographically dissimilar visual stimuli (pictures-to-words) and that the trained responses, with the incorporation of MET, can lead to the emergence of derived relational responses, or discriminations, and that the responding can generalize to novel stimuli. However, it is possible that a participant in the current study learned the rule that describes different types of graphs and then used that rule to identify the extent of functional relation demonstrated by other graphs. Given the fact that the graph-to-functional relation statement discrimination emerged for all participants and generalized to novel stimuli, it is reasonable to question whether some part of that performance was due to the emergence of a relation not only among the three stimuli in the functional relation statement class, but also among the verbal stimuli in the rule itself (Barnes-Holmes et al., 2002; Tarbox, Tarbox, & O’Hora, 2009; Tarbox, Zuckerman, Bishop, Olive, & O’Hora, 2011). The slight increases in pretest scores for Participants 2 and 4 might also be explained by the use of verbal problem-solving skills and/or the participants’ history with written selection-based assessments (i.e., multiple choice tests). However, future research in this area, specifically with EBI for written visual stimuli in applied settings, is warranted.

Although the results of the current study demonstrated that EBI was used to teach a fairly complex behavior analytic skill, the skill itself is not exactly the behavior that clinicians engage in when they are analyzing data graphs. Analyzing data in actual clinical settings is much more complicated and nuanced than the analysis of the graphs that was demonstrated in the current study. Additionally, the actual verbal behavior (either covert or overt) that a participant engaged in during the analysis was not measured or assessed. For example, at the conclusion of the training, a participant could have been asked to describe the graph, and the participant’s response could have been compared to the rule that was directly taught. Future research should assess a participant’s verbal behavior when engaging in analytic activities, not just visually analyzing graphs. In addition, future studies should test for the emergence of untrained topographical responses (Reyes-Giordano & Fienup, 2015) including written and vocal tacts of particular aspects of the graph (i.e., identifying level, trend, and variability) and tacts of the level of functional relation itself. This line of research would provide further distinction between the establishment of equivalence classes as a result of conditional discrimination performances without verbal behavior and performances with the use of verbal behavior (Jennings & Miguel, 2017; Petursdottir, Carp, Peterson, & Lepper, 2015).
Complex human behavior has been under both theoretical and experimental investigation since the dawn of mankind. Traditional approaches tend to be based on a priori assumptions and appeals to mentalistic constructs that leave both the scientist and practitioner with an empirically unsupported foundation upon which to build a set of teaching principles and protocols. However, data from studies like the current investigation allow both scientist and practitioner to better understand and apply tools such as EBI and MET when training complex human behavior. However, this area is admittedly open for conceptual analysis, and the field of behavior analysis is strongly encouraged to engage in this conversation. More research needs to be conducted, and much like the training procedures themselves, only with multiple exemplars of research studies will a clear and concise conceptual understanding of complex human behavior, along with practical and empirically supported technologies to train behavior analysts, ultimately emerge.

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