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TEACHING BRAIN–BEHAVIOR RELATIONS ECONOMICALLY WITH STIMULUS EQUIVALENCE TECHNOLOGY

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Instructional interventions based on stimulus equivalence provide learners with the opportunity to acquire skills that are not directly taught, thereby improving the efficiency of instructional efforts. The present report describes a study in which equivalence-based instruction was used to teach college students facts regarding brain anatomy and function. The instruction involved creating two classes of stimuli that students understood as being related. Because the two classes shared a common member, they spontaneously merged, thereby increasing the yield of emergent relations. Overall, students mastered more than twice as many facts as were explicitly taught, thus demonstrating the potential of equivalence-based instruction to reduce the amount of student investment that is required to master advanced academic topics.

Key words: college students, neuroanatomy, programmed instruction, stimulus equivalence

Instructional interventions based on stimulus equivalence and related principles of stimulus class formation (hereafter called equivalence-based instruction or EBI) focus on teaching generatively, that is, giving students the conceptual building blocks that allow them to reliably "go beyond the information given" (Bruner, 1957; p. 41). The defining feature of EBI is that students learn overlapping conditional discriminations that promote the formation of additional, unpracticed abilities (e.g., Critchfield & Fienup, 2008; Green & Saunders, 1998; Sidman, 1994; Stromer, Mackay, & Stoddard, 1992). For example, having learned to associate the spoken word "cat" with both a photograph of a cat and the printed word *cat*, a child may be able without further teaching to relate the cat picture to the printed word *cat*, even though the child has never experienced these together (e.g., see Sidman & Cresson, 1973). This suggests that the picture and the spoken and printed words have become functionally interchangeable (i.e., the items are recognized as "belonging together" or "meaning the same thing"). In the language of stimulus equivalence, the emergent ability to relate stimuli that were not previously paired, but that share a common associate, is called *transitivity* (Sidman) or *transitive inference*. Transitive inferences are expected to emerge reliably only if certain foundational facts are learned and only if these reflect overlapping conditional discriminations (Sidman).

Principles of stimulus class formation have been applied mainly toward enhancing the repertoires of young children and persons with developmental disabilities. Relevant academic instruction (for a seminal review, see Stromer et al., 1992) has, therefore, focused on basic academic repertoires such as translating between fractions and decimals (Lynch & Cuvo, 1995), identifying letters (Connell & Witt, 2004; Lane & Critchfield, 1998a) or words (de Rose, de Souza, & Hannah, 1996), and translating between English and Spanish words (Joyce & Joyce, 1993). In recent years, applications also have emerged that focus on basic social and communicative abilities (e.g., Pérez-González, García-Asenjo, Williams, & Carnerero, 2007; Rosales & Rehfeldt, 2007).

The published literature includes few instances in which sophisticated academic material was

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taught to advanced learners using techniques based on research on stimulus classes (Fields et al., 2009). We are aware of only two relevant reports, in which college students learned algebra skills through a combination of spoken instruction and stimulus class formation (Ninness et al., 2005, 2006). The dearth of applications with sophisticated learners might not appear to be much of an oversight if it is assumed that such learners require little academic assistance. Yet, as learner capability increases, so does the complexity of academic subjects. Consider, for example, the challenge of instructing college students about the biological bases of behavior (see Wilson et al., 2000). Even an elementary textbook on this topic contains many hundreds of unfamiliar terms and concepts related to neuroanatomy and the biochemical functioning of brain regions and individual neurons (e.g., Carlson, 2005). Each anatomical feature must be understood in relation to its various physical and functional characteristics. Couple this with the typical college course schedule, which includes only a few hours per week of formal instruction, and it is easy to see why even in advanced academic programs it is important to get the most out of limited instructional time (e.g., Chew, 2008). The present study illustrates how this may be achieved through stimulus class formation.

One key feature of the present study was an attempt to promote generative responding through a phenomenon called *class merger,* in which two stimulus equivalence classes sharing a common member spontaneously merge to form one larger class (Fienup & Dixon, 2006; Sidman, Kirk, & Willson-Morris, 1985). Class mergers increase the number of potential relations among facts that have never been directly paired (i.e., more emergent relations; see Lane & Critchfield, 1998b). Nevertheless, this tactic of arranging for class mergers to develop more relations than those taught rarely has been employed to academic advantage. To illustrate the potential benefits, consider a study by Lane and Critchfield (1998a) in which children with Down syndrome were taught relations between written vowels and the spoken label "vowel" (parallel instruction also was used to teach relations involving consonants). For example, the children were explicitly taught to match "vowel" to the letter A and A to the letter O. Without further training, they could also match O and "vowel" (transitivity). In the same way the children mastered a class consisting of "vowel" and the letters E and U. Because two vowel classes shared a common member (A), they merged to form one larger class (A-O-E-U-"vowel"), thereby allowing the children to match additional vowels that had never been paired directly during training (e.g., E and A).

The present study used EBI to establish relations among brain regions, their anatomical locations, and psychological functions and psychological problems associated with them. For efficiency, a few carefully selected relations were taught with the goal of promoting the emergence of several untaught relations that would increase the number of relations learned above the number of relations explicitly taught (e.g., Fienup & Dixon, 2006; Sidman et al., 1985). Four classes of five learning stimuli each (defined in Figure 1 and denoted here as A, B, C, D, and E) were employed to which the participants were not exposed. Each represented a lobe of the brain, and two small classes were established for each (A-B-C and A-D-E), both of which incorporated emergent potential. It was expected that students would spontaneously treat the B and C stimuli as "belonging with" the D and E stimuli (i.e., new relations would emerge) because the two classes shared a member (A).

METHOD

Participants

Eight college undergraduates volunteered after reading a flier posted on a recruitment bulletin board and participated after providing

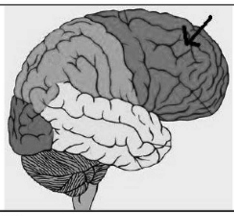
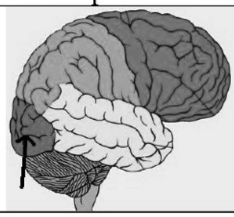
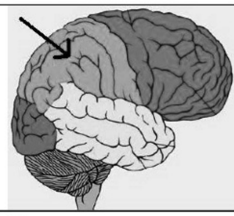
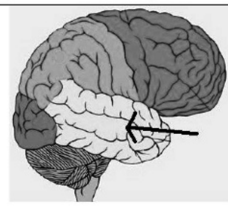
	Set 1	Set 2	Set 3	Set 4
A	Frontal Lobe	Occipital Lobe	Parietal Lobe	Temporal Lobe
B	Function 1: Involved in movement	Function 1: Involved in perceiving visual information	Function 1: Involved in perceiving touch	Function 1: Involved in auditory processing
C	Function 2: Involved in higher cognitive functions	Function 2: Involved in integrating color and shape	Function 2: Involved in integrating sensations	Function 2: Involved in memory formation
D				
E	Damage causes impulsiveness	Damage causes problems with sight	Damage causes inability to perceive objects in space	Damage causes memory and hearing impairment

Figure 1. Stimuli used in the study. See text for details of how stimuli were displayed.

informed consent. In exchange for participating, they received vouchers that could be exchanged for bonus credit in psychology courses. Volunteers were retained in the study if they scored below 70% on all of the pretests. This criterion was used to avoid ceiling effects that could preclude evidence that the experimental procedures promoted learning. No data are reported for 4 individuals whose pretest scores indicated existing mastery of the material to be taught. The 4 remaining students ranged in age from 18 to 22 years (M = 20.3, SD = 1.7). Participants appeared to be roughly typical of undergraduates at the university at which the research was conducted based on self-reported college grade point averages (range, 2.4 to 3.7) and ACT college-entrance examination scores (range, 21 to 27). Although college students often serve as participants of convenience in behavioral research (e.g., Ecott & Critchfield, 2004), in the present study college students were the population of practical interest.

Setting and Materials

Equipment. The study took place in a classroom equipped with 30 computer workstations, with multiple students working simultaneously. Instructional testing and training procedures were automated using a custom-written computer program created with Visual Basic 2005 (Dixon & MacLin, 2003). Each student worked on an IBM-compatible desktop computer (with a 15-in. flat panel monitor, keyboard, and mouse) that ran on the Microsoft Windows XP operating system.

Learning and feedback stimuli. Figure 2 reproduces key features of the computer display that students viewed during the lessons. Learning stimuli were presented in black Arial font (24 to 28 point) within white boxes (approximately 7.6 cm by 7.6 cm). For all training and testing, one box was presented at the top of the screen as a sample stimulus and four boxes below as comparison stimuli. In the top right corner of the participant's screen was a visual feedback box. During training the box dis-

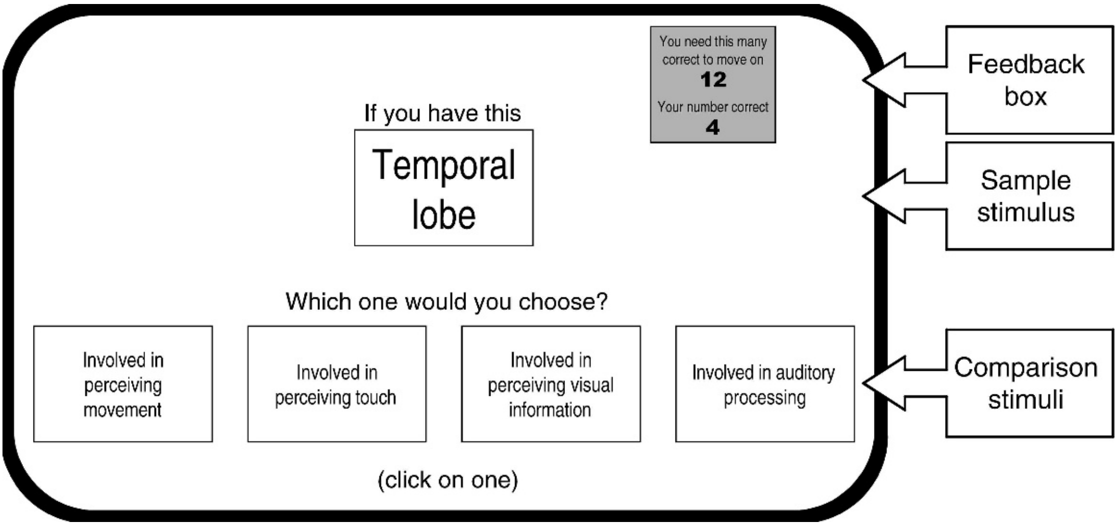


Figure 2. Participant's display, with example stimuli, as it appeared during training phases.

played the mastery criterion and success towards mastery. During testing the box displayed the number of trials on the test and the trial number the participant was currently completing.

During training phases, auditory accuracy feedback was provided through stereo headphones. Correct responses were followed by an ascending sound, and incorrect responses were followed by a descending sound (called a *chime* and *chord,* respectively, in the Windows XP operating system). No accuracy feedback was provided during testing.

General Procedure

General instructions, provided before the study began, described the computerized lessons as in development for eventual classroom use. The students were told that while working on the lessons they would complete pretests, training sessions, and posttests; that a score of at least 90% was required on each posttest to continue to the next part of the experiment; and that they would be excused from the study after 2 hr or completion of all of the lessons, whichever came first. Instructions did not, however, describe the stimuli used in the lessons or the relations among them that would be taught.

Overview of lessons. The students completed two lessons, each focusing on a unique aspect of the subject matter to be taught and each consisting of a pretest, training, and a posttest. The pretest and posttest of each lesson were identical. The computer program recorded the amount of time that students spent engaged with the training phase of each lesson (omitting nonlesson activities such as informed consent, instructions provided by the researcher, and transitions between tasks).

The lessons consisted of a series of trials in a match-to-sample format (Green & Saunders, 1998; Stromer et al., 1992). Each trial presented a sample stimulus (the question), which appeared near the top of the student's screen, and up to four comparison stimuli (possible answers), which appeared in the bottom row of boxes (see Figure 2). One comparison stimulus was the correct response, and the remaining stimuli were incorrect. The sample and comparison stimuli were presented simultaneously, and both stimuli remained on the screen until the student made a response to a comparison stimulus. During training portions of the study, clicking on any comparison box immediately produced auditory and visual accuracy feedback (described above) followed by the next trial (no intertrial interval). During testing portions of the study, clicking on any comparison stimulus immediately produced visual progress feedback.

To complete a lesson, a student had to demonstrate competence both during training and on the posttest. During training, mastery was defined as making 12 consecutive correct responses during a given learning unit (e.g., A→B). The cumulative probability of selecting the correct one on 12 consecutive trials was $.5^{12}$ (.0002) or $.25^{12}$ (.00000006) given two or four comparison stimuli, respectively, on each trial. On this basis, the mastery criterion was deemed adequate for distinguishing between genuine mastery and spurious runs of correct responses. Once a student achieved mastery of the training portion of a lesson, an on-screen message declared, "You have passed! Click this button to continue." Clicking on this button began the next scheduled part of the procedure.

For posttests, mastery was defined as scoring at least 90% correct. A lower score initiated remediation in which the training portion of the lesson was repeated, after completion of which the posttest was readministered. After the posttest mastery criterion had been met, the student proceeded to the next scheduled portion of the study.

Randomization of trials. During both training and testing, the positions of the comparison stimuli were randomized such that each possible comparison stimulus was equally likely to be assigned to each possible screen location. The trials that comprised the testing phases of each lesson (pretest and posttest) occurred in a unique, randomized order for each student; however, each student experienced the same number of trials and exposure to different relations. During training involving learning units with two trial types (e.g., A1→B1, A2→B2), the order was randomized every two trials (e.g., either A1→B1 followed by A2→B2 or vice versa). This resulted in no more than two consecutive trials involving the same sample stimulus and ensured that the students gained approximately the same amount of experience with each of the stimulus relations being taught.

Overview of research design. The three stimulus sets were A-B-C (Lesson 1), A-D-E (Lesson 2), and B-C-D-E (relations between Lessons 1 and 2). Figure 3 displays the order in which testing and training were staggered. This design is similar to that employed by Fienup and Dixon (2006) and was implemented on an individual basis. The experimental design followed the general logic of multiple baseline and multiple probe experiments, in which abilities are measured at several times to determine whether changes correspond to the introduction of an intervention (Johnston & Pennypacker, 1980). The study began by pretesting the Lesson 1 and 2 relations followed by training on Lesson 1 relations. Following the mastery of Lesson 1, Lesson 2 and the B-C-D-E relations were tested. This served as a control to help attribute the change in Lesson 1 scores to the instruction provided. Then, Lesson 2 instruction was implemented to replicate the effects of EBI on generative responding.

Note on symmetrical relations. The training and testing phases of the study omitted symmetrical variants of explicitly taught relations (e.g., A→B was taught and tested, but not B→A). We assumed that, for the skilled learners on whom this study focused, competence on the trained relations implied competence on symmetrical variants (e.g., Fields & Reeve, 1997). This approach also allowed us to limit the number of trials in the training and testing phases. When examining potential transitive associations among stimuli that had not previously been paired, however, we tested the two symmetrical forms of relevant relations (e.g., B as sample with C as comparison, and C as sample with B as comparison) and treated each form as a separate relation. This approach

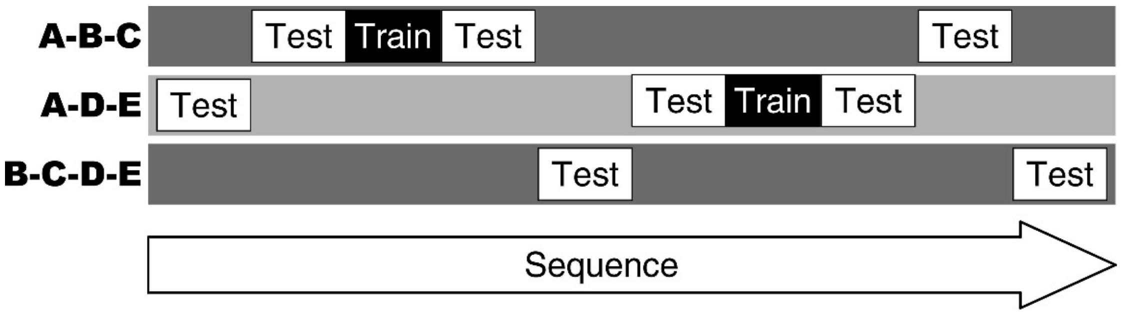


Figure 3. Schematic showing the sequence of training and testing phases of the study.

was based on the common assumption that for both of these to emerge, the learner must have mastered the symmetrical version of each trained relation (e.g., Sidman, 1994).

Lesson 1 (Lobes and Functions): A-B-C Relations

In this lesson students learned how the following stimuli (textual descriptions) relate: names of brain lobes (A stimuli), a psychological function associated with the respective brain lobes (B stimuli), and a second function associated with the respective brain lobes (C stimuli). Figure 1 displays the stimuli, Table 1 shows the specific trials presented in each phase of training, and Figure 4 (top left) shows the basic structure of training and testing, with trained relations depicted via black arrows and expected emergent transitive associations depicted via gray arrows.

A→B training. The students learned four A→B relations. The sample stimuli were brain lobe names (e.g., *frontal lobe*) and comparison stimuli were brain functions (e.g., *Function 1: Involved in movement*). Training occurred in three blocks of trials, each of which had to be mastered separately. The first training block involved A1→B1 and A2→B2 trials, with B1 and B2 serving as comparisons along with two blank boxes. The second block involved A3→B3 and A4→B4 relations, with B3 and B4 serving as comparisons along with two blank boxes. In the third block all four A→B relations were intermingled in a block of trials, with all B stimuli presented as comparisons.

A→C training. The students learned four A→C relations. For this training the sample stimuli were brain lobe names (e.g., *frontal lobe*) and comparison stimuli were additional brain functions (e.g., *Function 2: Involved in higher cognitive functions*). A→C training was similar to A→B training. Training occurred in three blocks of trials that had to be mastered separately. The first involved A1→C1 and A2→C2 relations, the second involved A3→C3 and A4→C4 relations, and the third involved all four A→C relations.

A-B-C pretest and posttest. The following transitive relations were tested: four B→C relations and four C→B relations. The test included four trials of each relation type, for a total of 32 trials. All four possible comparison stimuli appeared on each trial (e.g., for B→C relations the comparison stimuli always were C1, C2, C3, and C4).

Lesson 2 (Lobes, Locations, and Disorders): A-D-E Relations

In this lesson the students learned how the following stimuli (pictures and textual descriptions) relate: brain lobe name (A stimuli), an anatomical location of the respective brain lobe represented by a colored drawing (D stimuli), and an effect (disorder) that can arise due to damage to the respective brain lobe (E stimuli). Figure 1 shows the stimuli that were involved,

Table 1
Training Sequence

Condition	Phase	Sample/correct comparison	All comparisons
A→B training	1	A1→B1 and A2→B2	B1 and B2
	2	A3→B3 and A4→B4	B3 and B4
	3	A1→B1 and A2→B2 A3→B3 and A4→B4	B1, B2, B3, B4
A→C training	1	A1→C1 and A2→C2	C1 and C2
	2	A3→C3 and A4→C4	C3 and C4
	3	A1→C1 and A2→C2 A3→C3 and A4→C4	C1, C2, C3, C4
A→D training	1	A1→D1 and A2→D2	D1 and D2
	2	A3→D3 and A4→D4	D3 and D4
	3	A1→D1 and A2→D2 A3→D3 and A4→D4	D1, D2, D3, D4
A→E training	1	A1→E1 and A2→E2	E1 and E2
	2	A3→E3 and A4→E4	E3 and E4
	3	A1→E1 and A2→E2 A3→E3 and A4→E4	E1, E2, E3, E4

Note. This table displays the trials that were presented in each phase of the study. For each type of relation (e.g., A→B, A→C) participants began MTS training with stimuli from Sets 1 and 2. Following mastery, participants completed training with Sets 3 and 4 followed by a phase with all four sets of stimuli presented (see Figure 1 for description of the stimuli).

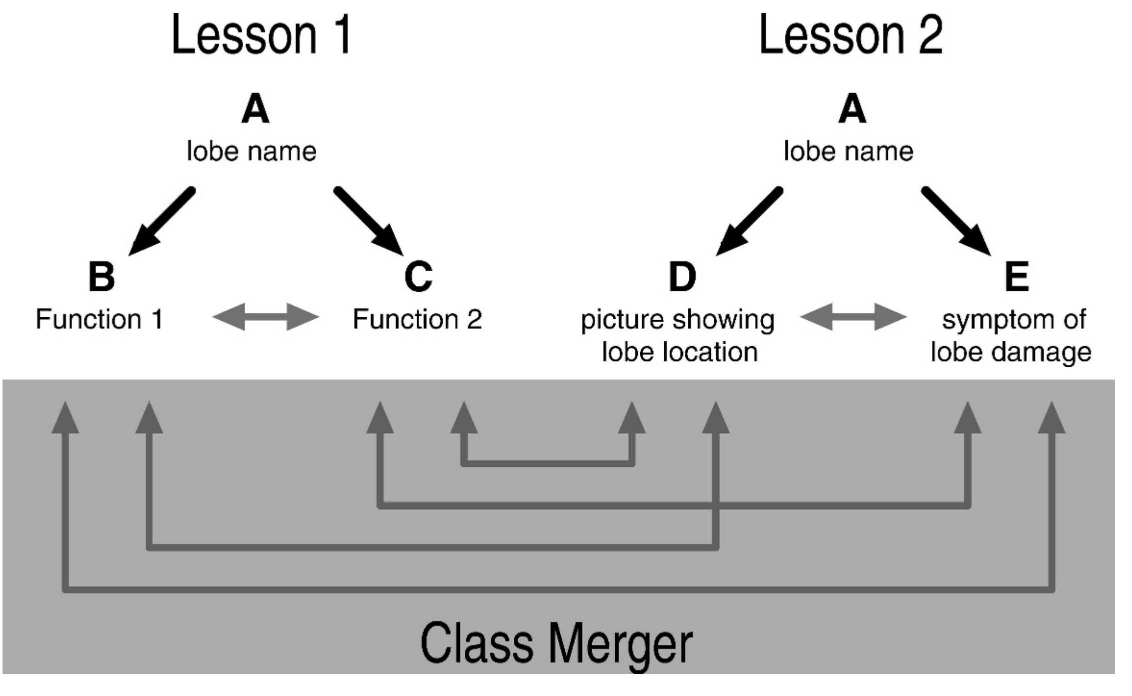


Figure 4. Top: structure of training and testing in the two lessons. Relations that were directly taught are shown as black arrows; transitive associations that were expected to emerge without direct training are shown as gray arrows. Bottom: structure of the test for class merger. Transitive associations that were expected to emerge without direct training are shown as gray arrows. Note that in each phase of the study, the relevant relations were included for four stimulus sets, each representing a different lobe of the brain.

and Figure 4 (top right) shows the basic structure of training and testing, which paralleled that of Lesson 1.

A→D training. The students learned four A→D relations. The sample stimuli were brain lobe names (e.g., *frontal lobe*), and comparison stimuli were pictures of the brain with the respective area highlighted. A→D training was similar to A→B training. Training occurred in three blocks of trials that had to be mastered separately. The first involved A1→D1 and A2→D2 relations, the second involved A3→D3 and A4→D4 relations, and the third block involved all four A→D relations.

A→E training. The students learned four A→E relations. For this training the sample stimuli were brain lobe names (e.g., *frontal lobe*) and comparison stimuli were statements about what could occur given damage to the respective brain region (e.g., *Damage causes impulsiveness*). A→E training was similar to A→B training. Training occurred in three blocks of trials that had to be mastered separately. The first involved A1→E1 and A2→E2 relations, the second involved A3→E3 and A4→E4 relations, and the third block involved all four A→E relations.

A-D-E pretest and posttest. The following transitive relations were tested: four D→E relations and four E→D relations. The test included four trials of each relation type, for a total of 32 trials. All four comparison stimuli appeared on each test trial (e.g., for D→E relations the comparison stimuli always were E1, E2, E3, and E4).

Class Merger Test: B-C-D-E

Lesson 1 established A-B-C relations, and Lesson 2 established A-D-E relations. If these two stimulus classes merged because of a shared member (A), then without explicit training the students would also be competent with novel B-C-D-E relations. Figure 4 (bottom) shows the transitive associations that were expected to emerge without direct training. Note that previous tests evaluated relations between the B and C stimuli and between the D and E stimuli. Thus, the novel relations on the class merger test were B→D (and D→B), B→E (and E→B), C→D (and D→C), and C→E (and E→C). All four possible comparison stimuli appeared on each trial (e.g., for B→D relations the comparison stimuli always were D1, D2, D3, and D4). Each relation was presented four times, resulting in 128 total trials (8 relations × 4 lobe classes × 4 trials each).

Students completed the class merger test on two occasions: prior to A-D-E training, before the lessons provided any basis for relating the A-B-C and A-D-E stimuli, and following A-D-E training and the posttests for A-B-C and A-D-E relations.

RESULTS

Results of pretests and posttests are summarized in Figure 5. Test outcomes are shown in terms of percent correct. Results of the trainings are summarized in Table 2 in terms of the number of trials and amount of time required in a given lesson to meet the mastery criteria. Because mastery was required prior to any posttest, the reader may assume, without inspecting the details of Table 2, that each student demonstrated mastery on each learning unit of each training phase.

Prior to any training, all of the students scored well below mastery for what would be the focus of Lesson 1 (A-B-C) or Lesson 2 (A-D-E). Data on the left side of the phase line of Figure 5 summarizes pretest results. Mean correct student responding on the A-D-E pretest was 50% and slightly higher on the A-B-C pretest. Subsequently, as Table 2 shows, all students completed Lesson 1 A-B-C training in 121 to 198 trials, including any remediation (see below); this required 10 to 13.5 min of engagement. On the ensuing test of emergent relations (data on the right side of the phase line of Figure 5) involving the B and C stimuli, Students 1 and 3 demonstrated mastery. Students 2 and 4 met the mastery criterion after failing a first attempt at the A-B-C posttest and repeating A-B-C training. At this time, no improvements were evident in A-D-E relations (Figure 5, middle), and no

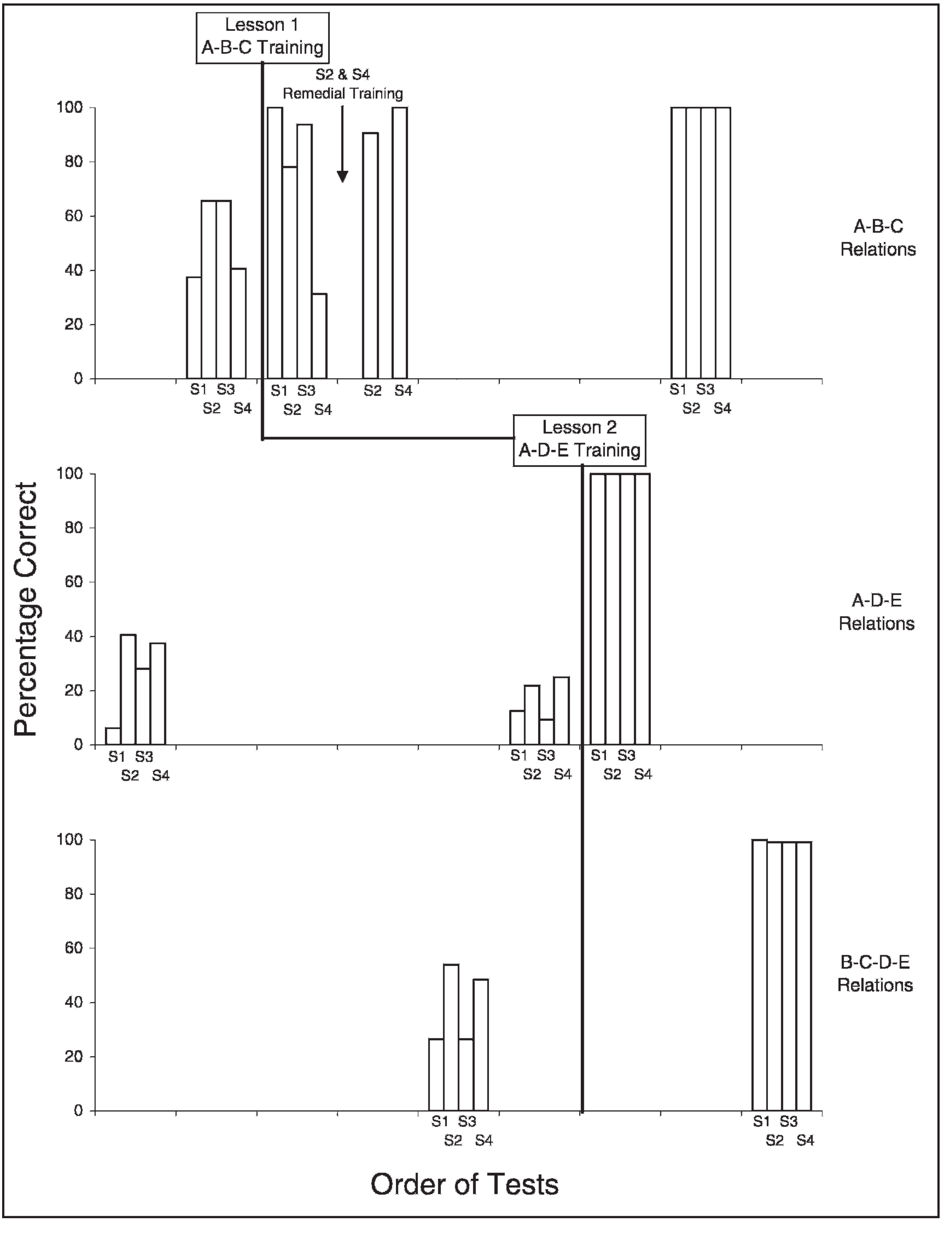


Figure 5. Performance on tests for taught (top and middle) and emergent relations (bottom).

Table 2
Requirements to Meet Mastery Criteria

Student	A1→B1, A2→B2	A3→B3, A4→B4	All A→B	A1→C1, A2→C2	A3→C3, A4→C4	All A→C	Total
Lesson 1 (A-B-C): number of trials							
1	12	22	91	12	26	35	198
2	13 (12)	21 (22)	12 (12)	16 (12)	12 (12)	24 (12)	180
3	12	12	60	12	13	12	121
4	19 (26)	27 (12)	13 (12)	13 (12)	12 (17)	12 (12)	187
Lesson 1 (A-B-C): time of engagement (s)							
1	34	50	431	37	55	196	803
2	50 (38)	69 (88)	43 (47)	48 (34)	31 (38)	95 (39)	620
3	92	39	318	60	55	44	608
4	53 (64)	66 (37)	64 (73)	65 (48)	39 (51)	60 (80)	700
Student	**A1→D1, A2→D2**	**A3→D3, A4→D4**	**All A→D**	**A1→E1, A2→E2**	**A3→E3, A4→E4**	**All A→E**	**Total**
Lesson 2 (A-D-E): number of trials							
1	21	15	14	17	14	12	93
2	12	12	12	12	12	12	72
3	13	13	12	13	12	12	75
4	17	13	12	12	12	21	87
Lesson 2 (A-D-E): time of engagement (s)							
1	32	25	31	43	34	33	198
2	31	34	22	26	36	30	179
3	28	37	21	43	27	34	190
4	21	26	27	31	42	66	213

Note. Numbers in parentheses represent remedial training that was required after a student failed a posttest. In such cases, the Total column includes both iterations of the training phase.

student showed substantial competence with B-C-D-E relations (Figure 5, bottom).

Next, all of the students completed Lesson 2 training (Table 2) in 72 to 93 trials (about 2 to 3.5 min of engagement). On the ensuing test of emergent relations involving the A-D-E stimuli, all students demonstrated mastery; thus, unlike in Lesson 1, no remedial training was needed. At this time all students also demonstrated that they had retained the benefits of Lesson 1 (Figure 5, rightmost columns, top), and that the stimulus classes of Lessons 1 and 2 had merged to create additional B-C-D-E emergent relations (Figure 5, rightmost columns, bottom). Accuracy was near 100% in all cases.

DISCUSSION

Results in Practical Context

To summarize the training, each of the computerized lessons taught two relations for each of four stimulus sets (each related to a brain lobe). The study's critical contribution regards the number of relations that that emerged without explicit training. Training promoted the emergence of four symmetrical relations (B→A, C→A, D→A, and E→A) that were not explicitly tested but theoretically must be in place for transitive relations to emerge (see Sidman, 1994) plus six transitive relations (B→C, B→D, B→E, C→D, C→E, and D→E) and their symmetrical variants (C→B, D→B, E→B, D→C, E→C, and E→D). If these symmetrical variants of transitive relations are treated as independent relations, as is the norm in basic research and in Sidman's (1994) stimulus equivalence theory, then the teaching of 16 relations (four for each of four brain-lobe classes) supported the emergence of 64 additional untaught relations (those just listed for each of four brain-lobe classes) or 80 total relations. Thus, students learned about five times as many relations as were expressly taught. In a more conservative accounting, in which each symmetrical pair of relations is considered as one relation, the teaching of 16 relations yielded 24 emergent relations (40 total relations), in which case students learned about two and a half times as many relations as were expressly taught. By either perspective, students were able to "go beyond the information given" (Bruner, 1957, p. 41) in precisely the ways that stimulus equivalence theory predicts. EBI thus delivered the generative responding that constitutes its major promise to education (Stromer et al., 1992). Given the technical nature of brain function and anatomy as an academic subject (Wilson et al., 2000), this was accomplished with surprisingly little student investment (e.g., about 13 to 17 min of engagement with the two lessons, excluding instructions, tests, and time in transition between activities).

To place the effectiveness of the lessons into a practical context, consider that the mastery criterion defined student success during training phases as 100% correct, which would count as a letter grade of A on any academic grading scale. Most likely this success was facilitated by generic features of good behavioral instruction, such as frequent student responding, frequent feedback, and individualized progress through the lessons (e.g., Keller, 1968; Skinner, 1968). On tests, which included only relations that had not been directly taught in the lessons, students had to score at least 90% correct (which would earn an A on most college grading scales) to move on to the next task. That they did so reliably underscores the novel (generative responding) contribution of EBI to behavioral instruction.

The multiple probes of the present experimental design were helpful in highlighting two outcomes of practical interest to the instructional designer. First, the relations that emerged among the stimuli of a given lesson were dependent specifically on the training of that lesson (i.e., Lesson 2 abilities did not improve until after Lesson 2 training). Second, the relations that emerged among the stimuli of the two separate lessons depended on the training of both lessons. Together, these findings support a maxim that Skinner (1968) advanced long ago but bears repeating: In building complex repertoires, it is important not to skip steps.

Although the students showed clear academic gains, including emergent ones, it is important to note that that this occurred in match-to-sample trials that emphasized selection-based responding. By contrast, many academic assignments in higher education require topography-based responding (e.g., this is a critical difference between multiple-choice and essay assignments), as do many professional tasks beyond higher education (e.g., writing a research report to submit for publication). Because topography-based responding was not assessed in the present study (or in the previously mentioned studies by Ninness et al., 2005, 2006), it is not known whether the repertoires established in selection-based procedures would contribute to student success on topography-based tasks. This defines an important direction for future EBI research.

Conceptual Issues

Class merger. The present study joins only a few others (e.g., Lane & Critchfield, 1998a) in suggesting that spontaneous class merger, promoted by classes that share a common member, may be academically beneficial. When two classes unite, emergent relations among their respective members become possible. Our study does not provide unequivocal evidence of class merger, however, because strictly speaking the term *merger* implies that two classes have existed independently prior to their union (Sidman, 1994). In the present study, the stimuli of Lessons 1 and 2 included a common member from the outset, so Lesson 2 might be described more conservatively as promoting the expansion of the classes that were created during Lesson 1. To demonstrate class merger unambiguously would require the creation of unrelated classes during initial lessons, followed by an additional lesson during which the shared associate was taught. The underlying distinction is important conceptually but possibly irrelevant to the instructional designer whose primary goal is to engineer new repertoires as efficiently as possible.

The role of verbal rules. Although EBI has been used to build new skills economically in people with learning difficulties and disorders, few studies have explored the utility of this kind of instruction for building high-level academic skills in typically developing individuals. Previous studies (Ninness et al., 2005, 2006) focused on mathematics skills; the present study extends the generality of EBI to brain–behavior relations. Unlike the studies by Ninness et al., however, this one was designed to evaluate EBI independently of instructor-generated verbal rules governing stimulus relations that are typical employed in a classroom environment. Specifically, Ninness et al. taught algebra skills via a treatment package that included explicit instructor descriptions of how various stimuli were related as well as relevant match-to-sample training (involving overlapping conditional discriminations, performance feedback, and mastery-level training). The lessons were effective, but the studies that evaluated them left unclear the relative contribution to student mastery of instructor-generated explanations and student practice with the component relations of stimulus classes. The current study is valuable in demonstrating that it is not always necessary to provide college students with rules about stimulus relations in order to use EBI successfully in teaching advanced material. Of course, given that the students were verbally capable, they could have generated their own rules. If so (our experiment was not designed to evaluate this possibility), then this may be viewed as another way in which EBI promotes "going beyond the information given."

Is this really stimulus equivalence? We have described the present lessons as exemplifying instruction based on equivalence relations, and it is worth clarifying what this assertion does and does not imply. Methodologically speaking, students responded to the academic stimuli in a fashion that was consistent with Sidman's (1994) theoretical account of equivalence. Most notably, the students transitively matched dissimilar stimuli, that is, they treated the stimuli as interchangeable to the extent that the instructional procedures allowed. This is not to say, however, that they would treat the same stimuli as interchangeable under all circumstances. For example, few reading-capable individuals would, in the abstract, judge that *frontal lobe* and *damage causes impulsiveness* "mean the same thing," and many situations may be imagined in which these phrases would be called "different." It is important to note that stimulus equivalence theory recognizes the potential for *contextual* control in which stimuli are equivalent in some circumstances but not others (Sidman). For example, *doberman* may be said to "go with" *poodle* and *bichon* in a discussion about the species *canus* but not in a discussion about specific dog breeds. Similarly, no theoretical contradiction exists in asserting that stimuli like *frontal lobe* and *damage causes impulsiveness* functioned as equivalent within the confines of the present lessons but are not unconditionally interchangeable.

Communicating about academic stimulus relations. The preceding discussion highlights two important points. The first point is that it is difficult to communicate about stimulus equivalence to a nonspecialist audience, which includes many readers of this journal. Lay euphemisms (e.g., "means the same thing") often are invoked in an attempt to ease the exposition because, on first blush, these seem to capture the general idea of stimulus equivalence. Yet such expressions may obscure important nuances of stimulus relations. Nothing in the present lessons indicated to students that *frontal lobe* "means the same thing" as *damage causes* *impulsiveness*; and, as noted above, stimulus equivalence theory does not make exactly this claim. Thus, lay vocabulary may carry unwanted conceptual baggage. As EBI interventions are developed for use outside of research settings, the need to communicate about them to nonspecialists will increase, and it is an open question as to whether the expositional benefits of lay expressions outweigh the potential for conceptual confusion that they introduce.

The second point worth stressing emphasizes a different way in which the learning stimuli may not "mean the same thing." To illustrate from the present study, note that *damage causes impulsiveness* is not a synonym of *frontal lobe* but rather a property of it. As relational frame theory (Hayes, Barnes-Holmes, & Roche, 2001) teaches, many types of relations (e.g., opposites, superordinate-subordinate, etc.) can spawn emergent abilities just as equivalence relations do. Thus, many types of stimulus relations could serve as the basis for instructional programming (e.g., Ninness et al., 2005, 2006). In the present article, our reliance on the language of stimulus equivalence was driven mainly by practical rather than theoretical concerns: This language mapped conveniently onto the instructional material, and it is somewhat familiar to the journal's audience. There is no question, however, that the present study could be interpreted within the framework of relational frame theory, and given the diversity of stimulus relations that academic curricula probably incorporate, a well-elaborated program of instruction could profit from drawing from the resources of both relational frame theory and stimulus equivalence theory.

Limitations and Future Directions

The present lessons were neither a complete program of instruction nor likely to promote sophisticated understanding of the targeted concepts. In the former case, the lessons taught only a few facts about brain anatomy and function from among the multitude that must be mastered in even an introductory course this topic (e.g., see Carlson, 2005), and it could be argued that resulting emergent relations did not really take students very far "beyond the information given" (Bruner, 1957, p. 41). Moreover, the "information given" was, as is often the case in introductory lessons, not very precise. Brain regions are interconnected and most psychological functions in which they participate are distributed across several regions (Carlson, 2005). Thus, the statements that served as this study's B, C, and E stimuli (Figure 1) are oversimplified. The present lessons are best appreciated, therefore, as an example of how to establish selected aspects of an entry-level higher education repertoire regarding brain structure and function. Subject-matter expertise would require considerable additional instruction. To concede this point does not contradict our assertion that the subject matter was more advanced than is normally seen in EBI investigations (consider, e.g., the challenges that might be encountered in teaching the same material to very young children or persons with developmental disabilities).

It should be noted as well that the learners in the present investigation were research volunteers whose learning was not linked to an academically sanctioned course of instruction. The study was intended to mimic college instruction in important ways (the learners were similar to students who typically would encounter the topic of instruction, and the lessons were administered to several students simultaneously in a computer-equipped classroom). Nevertheless, like all other published studies of EBI to date, the present one qualifies as a feasibility evaluation; that is, it demonstrated learning-economy benefits under well-controlled conditions. Whether similar lessons can have a significant impact on student progress through a course of instruction in a natural setting remains to be determined. From an evidence-based practice perspective (Chorpita, 2003), the empirical evaluation of an intervention considers two broad features: its efficacy (beneficial effects under controlled conditions) and its transportability (beneficial effects when extended to specific practice settings). The present study addresses efficacy. With respect to transportability, field studies, in which EBI is evaluated as a part of an ongoing instructional system, are needed to determine whether academic benefits that accrue in laboratory-like environments also can be engineered reliably under less ideal everyday circumstances.

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