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Anishka Madansingh

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An Analysis of Efficiency in Equivalence-Based Instruction in Higher Education

by

Anishka Madansingh

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Thesis Committee:
Benjamin N. Witts, Chairperson
Odessa Luna
Michele R. Traub

Abstract

Equivalence-based instruction (EBI) is a method of presenting instructional content based on the principles of stimulus equivalence. EBI has been demonstrated to be a successful method of teaching advanced academic content to students in the university setting. EBI procedures have been shown to be efficient when teaching a variety of academically relevant content when compared to an alternative teaching approach. The purpose of this study is to compare the efficiency of an EBI training package, where students will be taught and tested for derived relations to a complete instruction (CI) package, where students will be directly taught all targeted relations. A within-subject counterbalanced experimental design will be used to compare mastery of training outcomes across teaching arrangement, for each participant, and across participants with altered teaching arrangements. We hope to add to the current literature by expanding the parameters in which efficiency is evaluated when comparing EBI to alternative instructional methods in higher education.

Keywords: equivalence-based instruction, complete instruction, stimulus equivalence

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Chapter 1: Introduction

A post-secondary education has become an increasingly common prerequisite for many professions. As learner capability increases, so does the complexity of academic subjects. College students are expected to demonstrate immediate proficiency in complex academic material under the typical conditions of large lecture-style teaching. However, as Brodsky and Fienup (2018) reviewed, the traditional lecture format is usually applied with a reliance on aversive control of student performance. If a student fails to learn the material, the assumption is that the student is to blame, and the academic content is never at question. Furthermore, within the current educational system, students are passed through coursework without achieving full mastery of concepts, setting them up to be less prepared for each following stage in their educational career (Vargas & Vargas, 1991).

Behavioral Engineering of General Education

Behaviorists have an extensive history of improving educational practices. According to Skinner (1968), for teaching to be effective, it requires active, rather than passive learning. Skinner elaborated that teaching must be individualized, allow for frequent and immediate feedback, and be self-paced. He maintained that mastery of prerequisite material must be achieved before moving on to more difficult lessons, and recall must be directly reinforced for learning to occur (e.g., Skinner, 1954). To aid in this pursuit, Skinner developed a teaching machine to guide students through a series of self-paced lessons requiring them to respond actively to teaching and testing material. Skinner engineered his machines to compete with traditional teaching so that reinforcement was immediate, lesson progression was self-paced, and teaching materials required active responding.

Skinner’s technology was momentous in establishing teaching procedures that allowed for the control of educational behavior. In a description of teaching machines, Holland and Skinner (1961) emphasized the importance of preparing good teaching machine material, noting that it is uniquely controlled by the student’s response. Analyzing student responses allows teachers to precisely modify teaching mechanisms. They substantiated this claim with a description of an elaborate experiment testing this procedure with Harvard students. Student responses were thoroughly assessed, programming materials were modified to address deficiencies, and tested again. These modifications allowed for faster performance even in situations requiring remediation. The technology of teaching machines was the first of its kind to allow programmers to assess teaching material and make revisions based on student effort. The emphasis on student behavior set the tone for further expansion into modified educational practice.

The instructional format presented in the teaching machine became the basis for Skinner’s concept of Programmed Instruction (PI; Skinner, 1968). PI introduced an alternative approach to education and the transmission of information from teacher to student in a series of frames. As Vargas and Vargas (1991) explained, in PI, if a student does not learn the material, then the instructional framework must be reviewed and revised. In other words, a student’s outcome of success or failure at mastering teaching materials provides information on where the teacher might consider modifying future teaching materials; thus, PI is an iterative process.

The interest in behavior analytic technologies of teaching spanned a range of educational levels, from elementary education up through higher education. A prime early example of behavioral engineering of higher education materials rests with Holland and Skinner’s (1961) introductory textbook, which is a purely PI text. The interest in behavior analytic educational technologies has not slowed, and original areas continue to be explored as well as new avenues of interest.

Behavioral Engineering of Higher Education

PI established the foundation for further investigation into alternative teaching methods, especially in higher education. Over time, programming technologies became more advanced, as did the intended audience. In an early meta-analysis comparing PI methods in higher education, results confirmed that PI proved to be effective in the transmission of educational material, or at least no worse than conventional methods (Kulik et al., 1980). In their meta-analysis, Kulik et al. (1980) noticed a general trend in which less time was spent on learning activities in PI control groups. This implication suggests efficiency as a defining characteristic in the argument in favor of PI.

Since the 1980 meta-analysis, research on PI in higher education has continued. Kurbanoglu et al. (2006) found that self-paced programmed learning was more effective than a conventional lecture style in teaching a higher education chemistry course. Additionally, satisfaction reports showed that participants favoured PI over traditional approaches. Although PI is less represented in current literature, it is arguably the benchmark that sparked a generation of academics dedicated to investigating student-centered controls in advanced learners.

Research shifting away from traditional teaching in the classroom environment was further bolstered by Keller’s (1968) Personalized System of Instruction (PSI). Expanding on those before him, Keller (1968) stressed active student participation at their own pace as the foundation of a successful instructional method, with repeated exposure to learning material, repeated testing, and immediate feedback.

Keller’s instructional plan, challenging the conventional teaching mechanism, gained national recognition, and prompted the application of PSI in many universities and colleges. PSI has been expanded to computerized-instructional models, which also proved effective in bolstering student performance through the application of emergent learning (e.g., Pear & Crone-Todd, 1999). Keller (1968) argued that teaching methods should be presented in a generative manner to facilitate emergent learning. By facilitating teaching methods in a way that promotes generative concept formation, practitioners are saving on instructional time, therefore, demonstrating efficiency.

Emergent learning is important because it promotes efficiency (Critchfield & Twyman, 2014). For emergence to occur, careful consideration must be placed on what information is taught to maximize student efforts. Efficiency is achieved when the amount of information that is learned exceeds the amount taught. The most recent contribution to behavior-analytic higher education teaching approaches is found in equivalence-based instruction (EBI), a teaching process based on emergent learning through stimulus equivalence. Stimulus equivalence is described as the process of establishing relations between stimuli that have never been previously paired but share common elements. Early investigations have recognized stimulus equivalence as a valuable technique in teaching academically relevant concepts (Brodsky & Fienup, 2018). Because EBI is the basis of this paper, it will benefit from additional exploration.

EBI in Higher Education

Sidman and Cresson (1973) produced one of the earliest investigations applying stimulus equivalence frameworks to teach concepts to individuals living with disabilities. They used a match-to-sample (MTS) technique to develop equivalence classes between novel stimuli that had never been previously paired. Conditional relations were also derived between stimuli that had not been directly taught. In their study, participants were taught to select pictures in the presence of a spoken word and to select written words in response to spoken words. Through mastery of these taught relations (spoken word → picture, spoken word → written word), several untaught functionally equivalent relations were also established between stimuli that were not directly taught. For example, from spoken word to written word, and from written word to spoken word, amongst others.

EBI is most commonly described through the presentation of a mathematical equation stating if A=B, and B=C, then A=C. Specifically, if a person is taught a relation between A and B, and a relation between B and C, they should establish an emergent relation between A and C without being directly taught. When novel stimuli with previous commonalties come together to share a stimulus class, it is said that an equivalence class has developed (Green & Saunders, 1998). According to Blair et al. (2019), a stimulus equivalence class must demonstrate that a set of relations have emerged; reflexivity (A=A), symmetry (if A=B, then B=A), and transitivity (if A=B and B=C, then A=C).

Recently, a sizable collection of literature exploring EBI as a method in teaching advanced academic content in higher education has emerged, primarily using a match-to-sample procedure to teach and test for the emergence of stimulus equivalence relations. Ninness et al.

(2005) taught students at the college level advanced mathematical functions by presenting EBI under the control of a computer-based method. After training, participants demonstrated proficiency when tested through the presentation of novel pairings in complex variations.

Fields et al. (2009) investigated equivalence class formation between sophisticated statistical concepts in a college environment. Participants were presented with a variety of stimulus classes, each of which contained additional stimulus types. All participants in the study formed equivalence classes within all variations of statistic interactions and maintained them during probe testing. Similarly, Critchfield and Fienup (2010) used a computerized instructional mechanism to teach stimulus equivalence relations of concepts related to statistics and hypothesis decision making to students at the college level. Their study was designed as a preliminary step toward developing an instructional procedure based on stimulus equivalence to teach college students. They implemented their teaching intervention in a controlled environment and were able to establish stimulus relations between arbitrary stimuli and develop complex relations.

Pytte and Fienup (2012) applied EBI to teach advanced neuroanatomy concepts to undergraduate students. The initial goal of their study was to determine the effectiveness of EBI in establishing emergent, untaught relations in a large classroom environment. They recognized that most successful applications of EBI were conducted in laboratory settings. They hoped to add to the limited literature demonstrating that EBI was still an effective teaching method even in the presence of environmental distractors. They also hoped to expand on current literature by assessing teaching efficiency. As they expected, they found that EBI could be successfully applied in a natural teaching environment with a large population of students. They demonstrated that a careful selection of pairing materials can result in the emergence of spontaneous stimulus relations within a concept. This discovery was instrumental in launching an analysis of EBI as it relates to the concept of efficiency in teaching.

Efficiency of EBI in Higher Education

Literature has confirmed that EBI can effectively teach directly trained relations between advanced academic concepts. In the early development of his teaching machines, Skinner (1968) acknowledged that teaching must become more efficient. Most studies have shown that EBI is effective in producing learning outcomes. Currently, limited literature exists investigating the concept of efficiency.

Critchfield and Fienup (2008) suggested that the hallmark of instruction in the context of stimulus equivalence is efficiency. The term efficient can be described as the ability to produce or do something without wasting time or energy (Merriam-Webster’s Collegiate Dictionary, n.d.). The goal of any instructional intervention should be to allocate time efficiently (Pytte & Fienup, 2012). Instructions should be presented through a paradigm in which learning is maximized and time spent teaching is minimized. As Critchfield (2018) explains, college teaching would benefit by applying behavioral interventions related to emergent learning. By meticulously teaching a few concepts, untaught relations will develop, and over time, learning benefits will outweigh time spent on teaching.

In higher education. Fienup and Critchfield (2011) compared a stimulus equivalence group, where students participated in an EBI lesson (SE), a negative control group that received no instruction, and a positive control group (CI), where students were taught all relations directly Although both teaching styles achieved similar mastery outcomes, the teaching investment was greater in the CI group. By comparing performance outcomes of each group, they were able to demonstrate EBI as a more efficient instructional intervention when compared to alternative methods. The SE group, who practiced only some relations, performed as well on all tests as the CI group. In Lesson 1, CI participants practiced three times as many relations as the SE group. In addition to needing more trials, the CI participants also required more time to complete training in both Lesson 1 and 2.

Fienup et al., (2015) compared efficiency effects of a simple-to-complex protocol to a simultaneous training protocol. Simple-to-complex protocol introduces training and testing phases in a particular order where derived relations probes are presented only after a prerequisite relation has been established. In this sequence, a participant would be taught a reflective relation (A→B), tested for symmetry (B→A), taught a second reflexive relation (B→C), then tested for symmetry (C→B), transitivity (A→C) and equivalence (C→A). In contrast, a simultaneous protocol includes training of all baseline relations for each equivalence class sequentially. Efficiency was identified as total time for immediate emergence of equivalence classes. Within this study, they conducted two experiments, comparing three- and four-member equivalence classes. Results showed that using the simple-to-complex (EBI) mechanism was twice as fast in class formation on an immediate basis. Additionally, 100% of participants in this group immediately formed three- and four-member equivalence classes. Increasing the class size in experiment two had no effect on immediate class formation. Whereas participants trained on all relations were influenced by increasing class sizes, with only 42% of participants forming equivalence classes in the second experiment.

According to Fienup and Critchfield (2011), the best way to test for efficiency of an alternative teaching method is by comparing outcomes to traditional approaches. Therefore, the present investigation was designed to expand research on EBI by evaluating efficiency in a university comparison of EBI to complete instruction. We hope to model findings of Fienup et al. (2015) by testing for the emergence of derived relations between three-member stimulus equivalence classes using a simple-to-complex approach.

The current study sought to extend research on equivalence-based instruction by directly analyzing efficiency in a comparison of teaching methods. The purpose of this current study was to further evaluate the efficiency of computer-delivered EBI for teaching university-level academic content by testing for immediate emergence. Participants will be taught neurological and genetic disorders in an approach modeled after Fienup and Critchfield (2011) comparing an EBI training package, where students are taught and tested for derived relations, to a complete instruction group, where students are directly taught all targeted relations. We hope to also go beyond the current research on equivalence-based instruction by comparing outcomes of EBI and CI within lessons for each participant, and across participants when instructional arrangements are altered.

Chapter 2: Method

Design

A within-subject counterbalanced experimental design was used in this study to compare mastery of training content. Specifically, the design was an equivalence-based instruction (EBI) arrangement, testing for emergent untaught relations, and a complete instruction (CI) arrangement, in which all relations are directly taught. A second independent variable consisted of stimulus set 1 and 2 (see Table 1), which was counterbalanced between participants. A control phase was omitted based on Fienup and Critchfield's (2011) findings where a no-instruction group performed much more poorly than the EBI and CI groups.

Participants

Six undergrad students (five females, one male) enrolled at a medium-sized Midwestern university participated in this experiment. Participants ages ranged from 19 to 22 years old and all spoke English as their first language. Participant grade point average was 3.1, and all were obtaining degrees in psychology.

Participants were assigned to groups based on order of appearance in the lab. The first three participants composed Group A and the last three Group B. At the beginning of the session, participants read and signed a document of informed consent and a demographics questionnaire (See Appendix A and B). Participants were also allowed to opt out of the study at any time without consequence. In some cases, research credit hours were allotted for participation, and because of this participation in this experiment concluded after 60 minutes regardless of progress.

Setting and Materials

The experiment was conducted in one session and took place in a computer laboratory on the university campus. Participants were seated independently at a desktop computer that ran a custom program on PsychoPy3 (Peirce et al., 2019). Participants interacted with the program through a wired computer mouse, and all other computer peripheries (e.g., keyboard) were removed from reach. A research assistant was present in the computer lab during sessions. At the beginning of the experiment session, participants were provided with an instruction sheet including a brief description of the match-to-sample format and explained that testing trials would be presented at random throughout the session (See Appendix C).

Software

Trials consisted of a match to sample format presented on a computer program, similar to that described by Fienup et al. (2015). For both EBI and CI arrangements, the computer software presented a sample stimulus at the top of the screen and four comparison stimuli evenly distributed directly below. One comparison stimulus represented a direct relational response to the sample (e.g., A1 to B1), and the other three were not directly related (e.g., B2, B3, B4). Participants were asked to select the option that best relates to the sample. Each arrangement consisted of a series of training and testing (EBI) or training only (CI) trials. The order of sample stimulus presentation and the distribution of comparison stimuli across trials were randomized prior to coding but remained identical for all participants. For training trials, accuracy feedback was presented immediately after a comparison was selected as *correct* or *incorrect*. During testing trials, no accuracy feedback was presented.

Stimuli

EBI and CI trial progression were modeled after Fienup et al. (2015), with some variations. Experimental stimuli can be found in Table 1. Each stimulus set included three four-member classes. Stimulus set 1 (ABC) were related to neurological disorders. The A class was the disorder name and included four members (A1, A2, A3, A4). For example, A1 was "*neurosarcoidosis"*. The B class members were defining features and the C members were potential treatments associated with the disorder (i.e., B1, B2, B3, B4, C1, C2, C3, C4). For example, the defining feature of neurosarcoidosis was "*inflammation and abnormal cell deposits in the cranial and facial nerves, hypothalamus and pituitary glands"* (B1) and the potential treatment was *"radiation therapy"* (C1). Stimulus set 2 (DEF) included human genetic disorders and participants were taught to relate the disorder name (D), a defining feature of the disorder (E) and an associated gene (F), all of which included four members (D1, D2, D3, D4).

Response Measurement

For every match-to-sample trial, correct responding was defined as a participant selecting the correct comparison stimulus that related to the sample stimulus presented above. Incorrect responses were scored if participants selected any of the other three comparison stimuli. Data were collected on time and number of trials needed to complete testing and training trials in stimulus set 1 and stimulus set 2 for each participant under EBI and CI arrangements. Participant rate of responding was then derived from these data to provide a measure of efficiency. Finally, trial and time efficiency ratios were calculated by taking the post-test score, subtracting the pre-test score, and dividing that by either trials or time between the end of pre-testing and the beginning of post-testing. In brief, the efficiency ratio measures how much improvement in score is achieved either per trial or per minute in either EBI or CI arrangements and might prove to be a more sensitive measure of efficiency that accounts for pre-testing score.

Teaching and Testing Arrangements

3mix Pretest and Post-test

Modeled after Fienup et al. (2015), the 3mix pretests and post-tests were composed of 48 trials and sandwiched both EBI and CI arrangements. For each stimulus set, two trials of all potential stimulus relations for each of the four classes were presented. For example, for A→B[1] relations, 3mix presented two trials of the following class relations: A1→B1, A2→B2, A3→B3 and A4→B4. Participants completed the 3mix test before each lesson as a means of testing for pre-existing class formations and after to determine emergent and derived class formations. There was no criterion required for the 3mix post-test before moving to the next lesson set, However, for analysis purposes, a score of at least 43 of 48 correct responses on post-test would identify mastery of materials (modeled after Fienup et al., 2015). A score of 12 or lower would suggest responding at chance levels (e.g., 25% or worse, give four comparison stimuli).

Equivalence-based Instruction (EBI)

EBI is modeled after Fienup et al. (2015) and their superior simple-to-complex protocol. All participants completed their first stimulus set under the EBI arrangement. Under this arrangement, participants were explicitly taught certain relations (AB and AC) and tested for derived relations (BA, CA, BC, and CB). Specifics of the sequence of training and testing for participants in the EBI arrangement can be found in Appendix D.

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[1] For brevity, A, B, and C will be used, but can be substituted with D, E, and F for stimulus set 2

Similar to Fienup et al. (2015), both the A→B and A→C relations were taught in two phases. Phase 1 taught A1→B1 and A2→B2 to mastery and Phase 2 taught A3→B3 and A4→B to mastery. Mastery criterion for each phase was set at 12 consecutive correct responses in each phase (e.g., A1 to B1); unlike Fienup et al. (2015), a third phase mixing the first two phases was not used. Once mastery for A→B relations was achieved, a B→A symmetry test presented two trials of each pairing, requiring a mastery of 7 out of 8 trials before A→C training. After mastery of A→C training and C→A symmetry, a mixed symmetry probe (16 trials B→A and C→A symmetry relations) and an equivalence probe (16 trials of B→C and C→B equivalence relations) were presented to test for derived relations. Mastery criterion for both mixed symmetry and equivalence probes required at least 14 out of 16 correct. Failure on symmetry tests initiated remediation of the previous training session (e.g. failure on C→A initiated remediation of A→C), the mixed symmetry probe, or the equivalence probe initiated remediations to the first phase of A→B training. Mastery on the equivalence probe promoted the 3mix post-test, which did not allow for remediation.

Complete Instruction (CI)

In CI, all possible stimulus relations were taught in consecutive order. All participants were exposed to the CI arrangement after completing the EBI arrangement, and order of stimulus set was contingent on participant groupings. During training, participants learned relations in two phases, identical to training phases presented in the EBI arrangements. The CI arrangement included training on all the relations in the following order: A→B, B→A, A→C, C→A, B→C, C→B. After mastery criterion of 12 correct responses in each phase was achieved in all six training phases, the 3mix post-test was presented. Appendix D displays the sequence of training in the CI arrangement.

General Procedure

On experiment day, each participant arrived at the research lab, were greeted and seated at a desktop computer, which has already been logged into the online experiment software. The experimenter told participants that they would be completing two computerized lessons on genetic and neurological disorders, both including a pretest and post-test. Participants were informed that they should choose the best answer for each trial and that some trials may include feedback, while others may not. Participants were also be told that the experimenter will be present during the entire session to answer any questions or address any concerns.

After completing the university-approved IRB consent form and demographics questionnaire, participants reviewed brief instructions on the MTS procedure.

The first three participants (Group A) proceeded through the EBI arrangement with stimulus set 1 (neurological disorders), followed by the CI arrangement with stimulus set 2 (genetic disorders). Group B participants completed the EBI arrangement with stimulus set 2 (genetic disorders), followed by the CI arrangement with stimulus set 1 (neurological disorders). After completing both lessons, participants were thanked for their time and dismissed from the research study.

Chapter 3: Results

Group A results compare stimulus set 1 in EBI to stimulus set 2 in CI, and comprise Participants 1, 2, and 3. Data for response rates are found in Figure 1 and 2 and data for efficiency are in Figure 3. Efficiency ratios (described below) are available in Table 2. Response rate, timing, and efficiency ratio data are reported with pre- and post-test data omitted. Participant 1 completed the EBI training in 22.5 minutes and required 169 trials to form all equivalence classes; a rate of 7.5 responses per minute. We were unable to obtain trial and time efficiency data on stimulus set 2 for participant 1 because they did not complete the CI arrangement in the 60-minutes allotted for this experiment; however, for the trials they did complete in CI, they produced 6.9 responses per minute for CI.

Participant 2 required 381 trials and 22.0 minutes to master stimulus set 1 in the EBI arrangement; a rate of 17.2 responses per minute. Participant 2 completed 292 trials in 15.3 minutes in CI; a rate of 18.9 responses per minute. Data on efficiency ratios show that every trial ran in the EBI arrangement improved participant 2’s score by 0.10 and every minute spent improved scores by 1.81. Efficiency ratios in the CI arrangement were similar, with increases of 0.11 for each trial and 2.02 for each minute.

Participant 3 took 499 trials and 27.2 minutes to form stimulus classes in the EBI arrangement; a rate of 18.2 responses per minute. They required 204 trials and 11.6 minutes to form all equivalence classes in CI; a rate of 17.5 responses per minute. Efficiency ratio data shows that every trial ran in the EBI arrangement improved participant 3’s score by 0.08 and every minute spent improved scores by 1.50. CI arrangement data shows increases of 0.16 for each trial and 2.75 for every minute.

Group B results compare stimulus set 2 in EBI to stimulus set 2 in CI, and comprise Participants 4, 5, and 6. Participant 4 required 164 trials and 11.1 minutes to mastery stimulus set 2 in the EBI arrangement; a rate of 14.8 responses per minute. It took participant 4 232 trials and 20.7 minutes to complete the CI arrangement; a rate of 11.2 responses per minute. Data on efficiency ratios show that every trial ran in EBI improved scores by 0.13 and every minute spent improved scores by 1.90. Efficiency ratios in the CI arrangement were similar, with increases of 0.17 for each trial and 1.89 for each minute.

Participant 5 took 113 trials and 8.7 minutes to complete stimulus set 2 in the EBI arrangement; a rate of 12.9 responses per minute. Participant 5 completed 194 trials in 15.9 minutes in the CI arrangement; a rate of 12.2 responses per minute. Data on efficiency ratios show that every trial ran in EBI improved participant 5's score by 0.29 and every minute spent improved scores by 3.78. Efficiency ratios in the CI arrangement show that every trial improved scores by 0.04 and every minute spent improved scores by 0.50.

Participant 6 took 104 trials and 8.4 minutes to complete stimulus set 2 in the EBI arrangement, a rate of 12.3 responses per minute. Participant 6 completed 307 trials in 21.4 minutes in the CI arrangement; a rate of 14.4 responses per minute. Data on efficiency ratios show that every trial ran in the EBI arrangement improved their score by 0.28 and every minute spent improved scores by 3.42. Efficiency ratios in the CI arrangement show that every trial improved scores by 0.07 and every minute spent improved scores by 0.94.

Participant scores from pretest to post-test in Group A improved by an average of 85% under the EBI arrangement, compared to the CI arrangement where scores increased by an average of 67%. In Group B, participant scores from pretest to post-test improved by an average of 58% in the EBI arrangement, compared to CI, where scores increased by 69%.

Under the EBI arrangement, participants, on average, required 16.6 minutes to master the stimulus set, compared to an average of 16.9 minutes for the CI arrangement. Further, participants completed the EBI arrangement in 238 trials on average, compared to CI, requiring 245 trials.

Chapter 4: Discussion

This study extends the current literature by investigating the efficiency of EBI in a simple-to-complex format compared to a CI approach, for both neuroanatomy and genetic disorders concepts, whereas prior research only addressed the former. In the EBI arrangement, participants were trained on some relations, whereas in the CI arrangement, they were trained on all relations. This study also expanded the current literature by directly comparing outcomes of EBI and CI within lessons for individual participants, and between groups while altering stimulus sets between arrangements.

When comparing EBI to a CI approach, Fienup and Critchfield (2011) found that EBI was more efficient. Although similar levels of mastery were found in both groups, the CI group required more trials and time for mastery than those in EBI. The results of the current study join previous findings in demonstrating that the application of stimulus equivalence as a teaching method can be effective in promoting the emergence of derived relations among advanced academic concepts. Like many before us, we used equivalence-based and equivalence-related (i.e., CI) methods to teach classes of stimuli and found that all participant post-test scores were higher than pretest scores; in fact, consistent with prior research, all participants in this study achieved mastery at post-test in at least one arrangement (a score of at least 43 of 48 correct responses; modeled after Fienup et al., 2015).

Additionally, average time and number of trials required to complete training were greater under the CI arrangement, when compared to EBI. Like Fienup et al. (2011), we found that the EBI arrangement required slightly fewer trials than the CI arrangement. When analyzing efficiency, results showed that the EBI group spent less time in training and improved the most on post-test scores when compared to the CI arrangement.

Overall, participants in both Group A and B performed better on stimulus set 2 content than stimulus set 1 regardless of arrangement. These results suggest that participants found it less difficult to master the genetic disorder relations presented in stimulus set 2, and had more difficulty mastering the neurological concepts in stimulus set 1. This is a potential limitation in that stimulus sets might not have been equivalent in terms of difficulty, despite pilot testing suggesting otherwise.

Participant rate of responding was consistent for both EBI and CI arrangements. Even when academic material included lengthy descriptions and complicated clinical definitions (i.e., B stimuli), participants maintained consistent rates of responding, even in the second CI arrangement when fatigue might be a concern.

Perhaps the biggest strength of this study was the independent and exploratory nature of capturing efficiency measures. Most previous literature used time or number of trials as the only evidence to support claims of efficiency in EBI. However, it might be necessary to examine other aspects to capture efficiency. For example, suppose we are comparing two instructional methods to evaluate efficiency. If one participant required 100 trials to achieve mastery while another needed 200 trials we would be inclined to say the participant needing 100 trials had the more efficient method. Perhaps, however, our findings show that the first participant took 15 minutes to work through those 100 trials, while the second participant needed 30 minutes to complete their 200 trials. In this case, rate of responding is equivalence, and we would be unable to determine one method as being more efficient than the other. Now consider that we set mastery criterion at 48 correct out of 48 questions in a post test, and we compare this to degree of improvement from a pre-test score. Consider further that participant 1 had a pre-test score of 30 and participant 2 had a pre-test score of 5. In this case, for every one training trial, participant 1's post-test score improved by 0.18, whereas for participant 2, each training trial improved their score by 0.22. In other words, while rate of responding was the same (100 trials per 15 minutes), the return on investment per trial was greater for participant 2's method; more is learned per trial. This is the basis of our efficiency ratio.

In this study, we calculated efficiency ratios to measure how much learning was occurring for each participant, under each arrangement. Although we found efficiency ratios to be quite variable across teaching arrangements, the findings of the present investigation provide insight that further consideration should be made into what defines efficiency. By considering efficiency ratios, we can go beyond previously explored efficiency measurements and analyze participant improvement scores for every trial and every minute to determine how much academic learning is actually occurring under each arrangement.

In research, especially in evaluations of stimulus-equivalence, we source participants who have a low baseline; to determine effect. In practice, we might not have that luxury, and therefore, it is in our best interest to look at instructional methods that produce the greatest degree of student instructional gains; especially with a higher education population. University students are likely to have prior knowledge in subject areas before teaching begins. In considering these real-world scenarios, efficiency ratios allow us to analyze participant score increases as they proceed through each teaching arrangement.

The current study is not without limitations. This experiment included only three participants in each of the participant groups. Although a small sample size is rarely considered a hindrance to experimental outcomes in the field of behavior analysis, it does create potential for incomplete data. Participant 1 failed to complete the stimulus set training and testing for the CI arrangement, resulting in some of their data being omitted from the results. It is unknown whether these incomplete data would have had significantly affected overall experiment results, however, this gap in data might be considered a potentially limiting factor. Further, without more participants, we were unable to counterbalance the EBI and CI training arrangements.

The current study demonstrated the emergence of equivalence class relations between concepts like those taught in an introductory university course. However, the teaching arrangements presented in this experiment only taught a few, specific descriptive facts about neurological and genetic disorders, which may be considered as another limitation. Considering that our target audience was university students, it is assumed that students in an undergraduate university class would be required to learn far more conceptual relations over the course of a semester than those presented in this experiment.

The present investigation demonstrated that an EBI teaching arrangement was successful in establishing immediate emergence of equivalence classes. However, participants were not exposed to any follow-up to studies to identify retention of teaching materials. Future exploration is needed to identify long-term retention and generalizability of emergent relations. It is especially important for university students to maintain retention of teaching concepts, far longer than the initial exposure. To truly determine EBI as an efficient teaching method, investigation into generalization is imperative.

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Table 1

Experimental Stimuli

Stimulus set 1: Neurological disorder

Name (A)	Definition (B)	Potential Treatment (C)
Neurosarcoidosis	Inflammation and abnormal cell deposits in the cranial and facial nerves, hypothalamus and pituitary glands	Radiation therapy
Guillain-Barre Syndrome	Body's immune system attacks parts of the peripheral nervous system	Plasmapheresis
Amyotrophic lateral sclerosis	Degeneration of peripheral nerves outside the brain and muscles they control	Occupational therapy
Neuro-Bechet's disease	Blood vessel inflammation through the ventral brain stem	Azathioprine

Stimulus set 2: Genetic Disorders

Name (D)	Clinical Feature (E)	Gene (F)
Duchenne Muscular Dystrophy	Gradual degeneration of skeletal muscle, impaired heart and respiratory musculature	Dystrophin (DMD) deletion,
Gaucher Disease	Lipid metabolism enzyme accumulation in the liver, spleen and bone marrow	B-Glucosidase
Tay-Sachs Disease	Accumulation of the lipid GM2 ganglioside in neurons	B-Hexosaminidase
Marfan Syndrome	Abnormalities of the skeleton, heart, pulmonary system, skin and joints.	Fibrillin-1 gene (FBN1)

Note. Stimuli and 3-member classes for stimulus set 1 and stimulus set 2 used in both EBI and CI arrangements.

Table 2

Efficiency Ratios

	EBI Trials	EBI Time	CI Trials	CI Time
Participant 2	0.10	1.81	0.11	2.02
Participant 3	0.08	1.50	0.16	2.75
Participant 4	0.13	1.90	0.17	1.89
Participant 5	0.29	3.78	0.04	0.50
Participant 6	0.28	3.42	0.07	0.94

Note. This table demonstrates participant score increase per trial and per minute for each teaching arrangement. Participant 1 scores are omitted from this table due to incomplete data.

Figure 1

Rate of Responding for Participants in Group A Across Arrangements

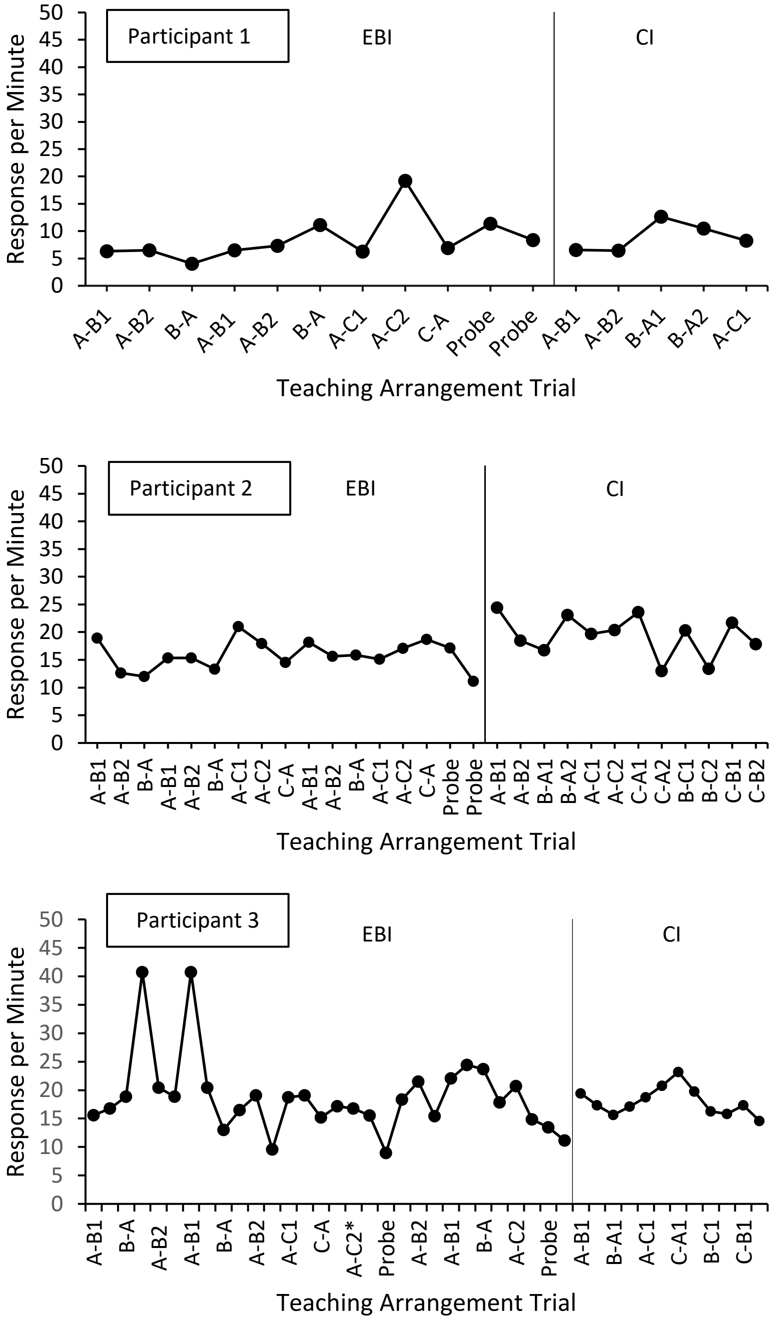


Figure 2

Rate of Responding for Participants in Group B Across Arrangements

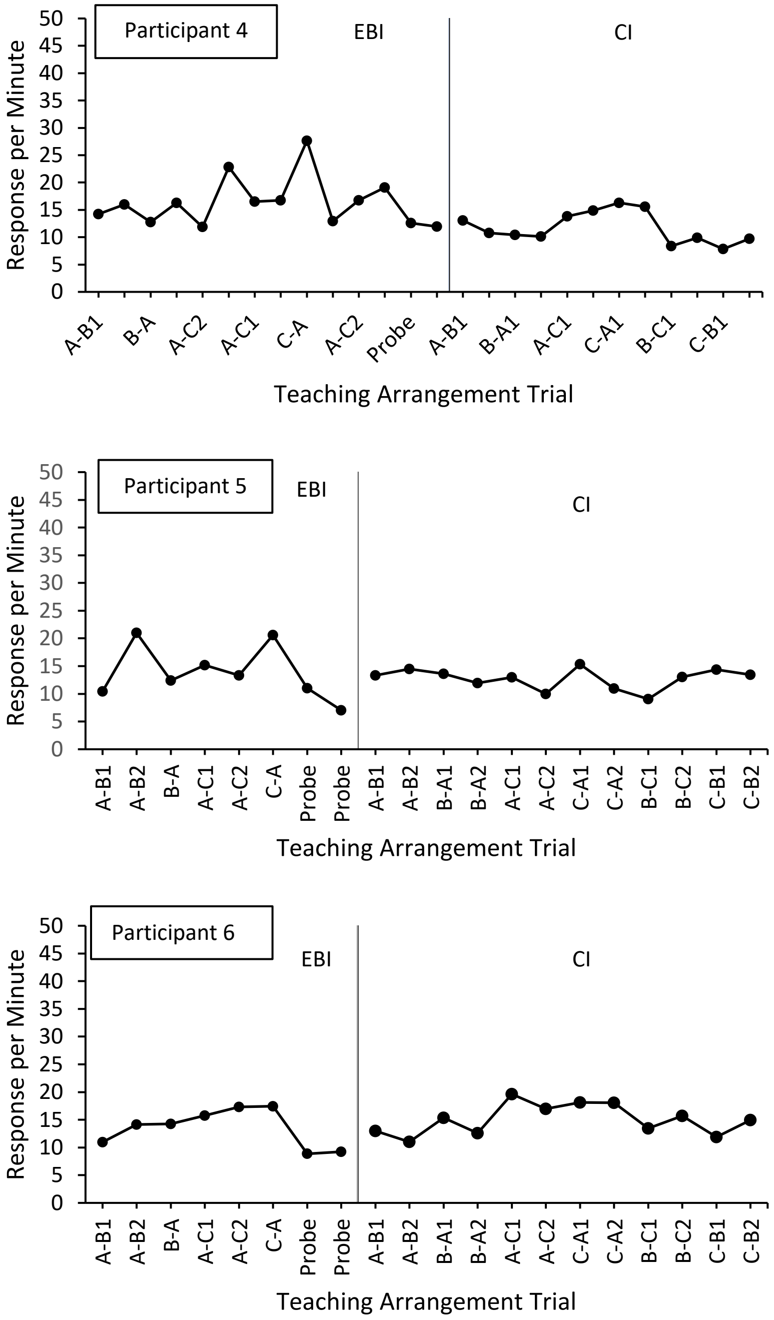
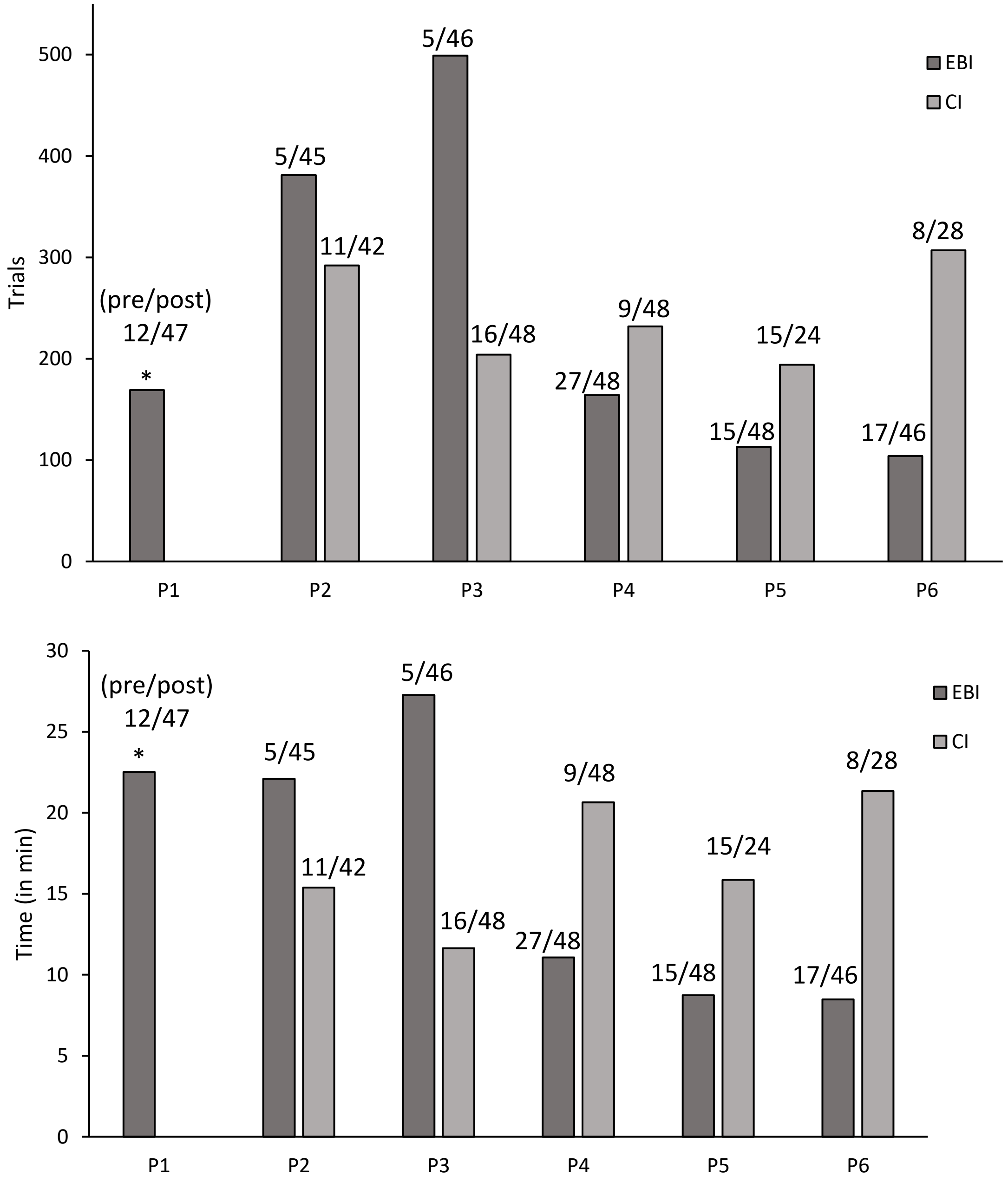


Figure 3

Number of Trials and Total Time to Complete Arrangements for All Participants



Note. Each participant pre-test and post-test scores are presented as a ratio above each bar graph. CI scores are omitted for Participant 1 as their experiment was incomplete.

Appendix A: Informed Consent Document

Title: Equivalence-Based Instruction in Higher Education

Primary Investigator: Anishka Madansingh (aw3580is@go.minnstate.edu)

Faculty Advisor: Dr. Benjamin Witts

Introduction

I am currently in my final year in the SCSU ABA graduate program, and this study is being conducted as part of my thesis requirement. I am asking for your participation in the study and ask that you read the following information before deciding to participate or not. If you have any questions, please don't hesitate to reach out.

General Procedure

If you choose to participate in this study, you can expect to take part in a series of simple computerizes lessons where you will be taught to match written words and pictures and then be asked to match the ones that best go together. The session will take place in the campus computer lab, with a researcher present and will be approximately 30-60 minutes. You may be contacted either two weeks or month later to participate in a 30-minute follow-up.

Risk and Discomforts

There are no known risks associated with participation in this research study.

Compensation

There is no direct compensation for participating in this research. In some cases, a faculty member might have offered extra credit for participating in this research study, in which case that credit will be determined by said faculty member.

Confidentiality

Your participation in this study will remain completely confidential in that any data we collect will only be associated with your assigned participant number. The only form that will contain your name and information will be this consent form. A researcher will be present virtually during the online session to observe participant behavior and answer any questions.

Voluntary Participation and Withdrawal

If you choose to participate in the proposed study, know that your participation is completely voluntary, and you may choose to withdraw at any point, with no need to provide rationale. Choosing to withdraw from the study will not provide adverse consequences and will not affect your affiliation with St. Cloud State University, the applied behavior analysis graduate program, or any of the researchers or faculty involved. If at any point you decide to withdraw from the study, alert any of the researchers on the team.

Acceptance to Participate

By typing my name, I verify that I have read and fully understand all risks and benefits associated with my participation in this study.

Name (First and Last): ____

Date: ____

Appendix B: Demographics Questionnaire

What is your age? ________________

What is your gender? ________________

What is your race/ethnicity? ______________

What language(s) do you speak fluently? _____________________

Approximately how many credits have you *completed*? __________________

What is your approximate GPA? ___________________

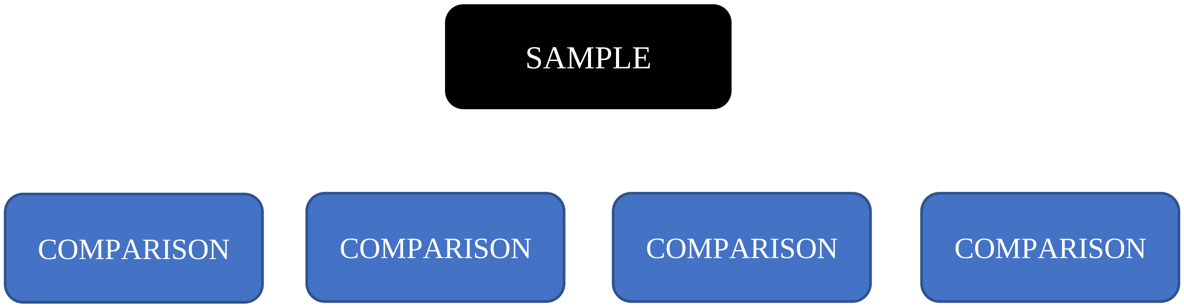
What is (are) your major(s)? _______________

What is (are) your minor(s)? _______________

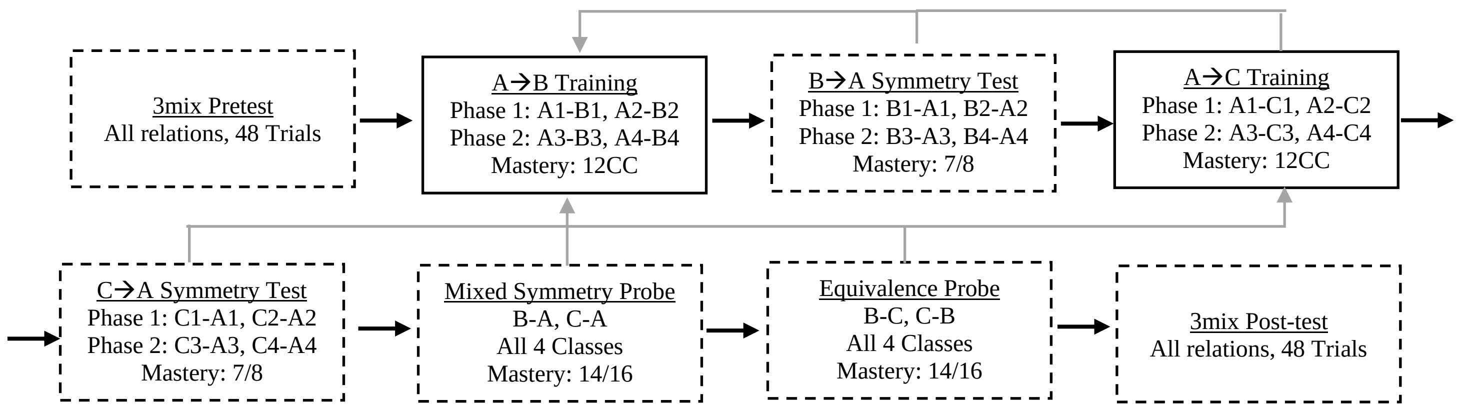
Appendix C: Match-to-sample Instructions

In this experiment, you will be presented with a series of “match-to-sample” tasks. In the middle of the screen, you will see a **sample** in a black square. You will then see multiple **comparisons** in blue squares displayed directly below. Click on the red square that “matches” the sample. On some trials you will receive feedback (correct or incorrect) and on some trials you will not.

This task will consist of two lessons, Lesson 1 will teach you neurological disorders, and Lesson 2 will teach you genetic disorders. Both lessons will include a simple pretest and post-test.



Appendix D: Equivalence-based Instruction Sequence



Complete Instruction Sequence