

July 2016

Truth Functions and Memory in English Language Learners

Eric Smiley Mr.

The University of Western Ontario

Supervisor

Dr. Steve Bird

The University of Western Ontario

Graduate Program in Education

A thesis submitted in partial fulfillment of the requirements for the degree in Master of Arts

© Eric Smiley Mr. 2016

Follow this and additional works at: <https://ir.lib.uwo.ca/etd>

 Part of the [Curriculum and Instruction Commons](#)

Recommended Citation

Smiley, Eric Mr., "Truth Functions and Memory in English Language Learners" (2016). *Electronic Thesis and Dissertation Repository*. 3830.

<https://ir.lib.uwo.ca/etd/3830>

This Dissertation/Thesis is brought to you for free and open access by Scholarship@Western. It has been accepted for inclusion in Electronic Thesis and Dissertation Repository by an authorized administrator of Scholarship@Western. For more information, please contact tadam@uwo.ca.

Abstract

English Language Learners (ELLs) are consistently found to overuse, misunderstand, and misuse connectives in the English language (Bolton et al., 2002; Chen, 2006; Hinkel, 2002; Ozono & Ito, 2003; Zhang, 2000) and current research has not investigated whether this misunderstanding affects the memory of claims. The primary goal of the present study was to examine whether knowledge of truth-functional connectives is related to conjunctive bias in ELL students. Using a within-subjects design, the effects of instruction in truth-functional connectives on conjunctive bias in nine ELL students were investigated. Repeated measures analyses of variance (ANOVA) revealed an elimination of conjunctive bias following explicit instruction in truth functions. Further tests were also conducted to validate instruments for measuring conjunctive bias, the understanding of truth functions, and to evaluate conjunctive bias and the understanding of truth functions among 29 ELL's. The findings have significant pedagogical implications related to the justification of including instruction in truth functions in language curriculum.

Keywords

English Language Learner (ELL), English Second Language (ESL), truth function, logical connective, English connective, memory, conjunctive bias, instructional intervention, mental model theory, logic, critical thinking, education, pedagogy.

Acknowledgments

First and foremost, I would like to acknowledge Dr. Steve Bird for his support throughout this thesis. His insight, experience, and general support were integral in the completion of this project and significantly contributed to making the project such a pleasure. I would like to thank Dr. Perry Klein, my thesis advisory committee member, for his time, instruction, and feedback throughout this degree. The staff and students at Western's English Language Centre and CultureWorks were integral in facilitating the instruction. Without your time and support this thesis would simply be conjecture. I would like to express my appreciation to Dr. Mark McCullagh for his mentorship in the area of logic and many other professors at the University of Guelph's Department of Philosophy who challenged and motivated me in the area of reasoning. Lastly, many thanks go out to the staff, faculty, and graduate students at the Faculty of Education who contributed to make this degree such a pleasant educational experience.

Table of Contents

Abstract.....	i
Acknowledgments.....	ii
Table of Contents.....	iii
List of Tables	vii
List of Figures	viii
List of Appendices	ix
Chapter 1 : Introduction and Fundamentals of the Thesis	1
1 Introduction	1
1.1 Literacy	4
1.2 Logic, Reasoning, and Literacy	5
1.3 Conjunctive Bias	9
Chapter 2 : Theoretical Framework	12
2 Theoretical Framework	12
Chapter 3 : Literature Review	14
3 Literature Review	14
3.1 Critical thinking.....	14
3.2 Critical thinking and literacy	15
3.3 Trends in critical thinking studies.....	16
3.4 Concerning conversational implicature	17
3.5 Logical connectives and mental model theory	23
3.6 Logical connectives and conjunctive bias.....	26
3.7 Logical connectives, comprehension, and English Language Learners	28

3.8 Transferring skills across domains.....	29
3.9 Summary of the literature	30
Chapter 4 : Methodology.....	32
4 Methodology.....	32
4.1 Phase 1A.....	34
4.1.1 <i>Participants</i>	35
4.1.2 <i>Materials</i>	35
4.1.3 <i>Design and procedure</i>	36
4.2 Phase 1B.....	38
4.2.1 <i>Participants</i>	38
4.2.2 <i>Materials</i>	39
4.2.3 <i>Design and procedure</i>	40
4.3 Phase 2.....	42
4.3.1 <i>Participants</i>	43
4.3.2 <i>Materials</i>	43
4.3.3 <i>Design and procedure</i>	44
4.4 Phase 3.....	46
4.4.1 <i>Participants</i>	46
4.4.2 <i>Materials</i>	46
4.4.3 <i>Design and procedure</i>	47
4.5 Phase 4.....	47
4.6 Phase 5.....	48
4.6.1 <i>Participants</i>	48
4.6.2 <i>Materials</i>	49

4.6.3 <i>Design and procedure</i>	49
Chapter 5 : Results	50
5 Results	50
5.1 Phase 1	50
5.1.1 Phase 1A	50
5.1.2 Phase 1B	52
5.2 Phase 2	55
5.3 Phase 3	57
5.4 Phase 4	60
5.5 Phase 5	61
Chapter 6 : Discussion	66
6 Discussion	66
6.1 Phase 1	67
6.1.1 <i>Phase 1A</i>	67
6.1.2 Phase 1B	68
6.2 Phase 2	70
6.3 Phase 3	73
6.4 Phase 4	75
6.5 Phase 5	76
6.6 General discussion	80
Chapter 7 : Conclusion	83
7 Conclusion	83
Chapter 8 : Contributions	84

8 Contributions	84
8.1 Research Literature	84
8.2 Pedagogical Implications	85
Chapter 9 : Limitations	88
9 Limitations	88
Chapter 10 : Recommendations for Future Research	90
10 Recommendations for Future Research	90
References	92
Appendix A	97
Appendix B	98
Appendix C	99
Appendix D	100
Appendix E	101
Appendix F	102
Curriculum Vitae	103

List of Tables

Table 1: List of Hypotheses	4
Table 2: Truth Functions of English Language Connectives.....	8
Table 3: Summary of Purpose and Pertinent Hypotheses for Each Phase.	33
Table 4: Summary of Completed Tests and Instruction for Each Phase.	34
Table 5: Means (<i>M</i>), standard deviation (<i>SD</i>), and number of participants (<i>n</i>) for language items in Phase 1A	51
Table 6: Means (<i>M</i>), standard error (<i>SE</i>), and number of participants (<i>n</i>) for acceptance rates of targets and different form foils in Phase 1B	54
Table 7: Means (<i>M</i>), standard deviation (<i>SD</i>), and participants (<i>n</i>) for pre- and post-test language items in Phase 2	56
Table 8: Means (<i>M</i>), standard deviation (<i>SD</i>), and number of participants (<i>n</i>) for language items in Phase 3.....	58
Table 9: Means (<i>M</i>), standard deviation (<i>SD</i>), and number of participants (<i>n</i>) for language items in Phase 4.....	60
Table 10: Means (<i>M</i>), standard error (<i>SE</i>), and number of participants (<i>n</i>) for acceptance rates of targets and different form foils in Phase 5.....	63

List of Figures

Figure 1: Rader and Sloutsky's (2001) presentation of conjunctive bias (p. 845)	28
Figure 2: Mean ELL student scores of truth function understanding.....	52
Figure 3: ELL student performance on the Test of Conjunctive Bias.....	54
Figure 4: Test of Claim Evaluation pre- and post-instruction scores.....	56
Figure 5: Comparison of pre- and post-test scores of each language item between instructional groups.	57
Figure 6: Effect of explicit instruction on mean truth-functional connective understanding .	59
Figure 7: Effect of explicit instruction on truth-functional connective understanding	59
Figure 8: Implicit-explicit instruction and explicit-only instruction groups understanding of truth-functional connectives.....	61
Figure 9: Conjunctive bias pre- and post- explicit instruction in truth functions	65

List of Appendices

Appendix A: Sample item from the Test of Claim Evaluation.....	97
Appendix B: Sample implicit instruction item.....	98
Appendix C: Sample explicit instruction item.....	99
Appendix D: Original Propositions for One Section of the Test of Conjunctive Bias.....	100

Chapter 1 : Introduction and Fundamentals of the Thesis

1 Introduction

Research on English Language Learners (ELL's) and logical connectives has focused primarily upon the effect of their presence in text and speech and the relationship between proficiency in English and comprehension or production of these various connectives. The consensus of the literature is that ELL's, regularly overuse, misunderstand, and misuse connectives in the English language (Bolton et al., 2002; Chen, 2006; Hinkel, 2002; Ozono & Ito, 2003; Zhang, 2000). However, despite the current understanding of this deficiency, there is little research on the effect that knowledge of logical connectives has on aspects of literacy, such as the ability to identify logical relationships within claims, what is required to make a given compound claim true or false (a skill concerned with the logical relationship *within* claims), and whether this requirement has an effect on our day-to-day understanding and use of our language.

This study focused on a particular grouping of logical connectives – truth-functional connectives. These are connectives such as an 'and', 'or', 'if, then', and 'if and only if' and each operates such that it has different requirements to be made true or false (See Logic, Reasoning, and Literacy, p. 5, for more information). As with other aspects of logical relations in natural language, the ability to understand and use truth-functional connectives is an important part of being a proficient user of a language because an understanding of these functions allows us to comprehend when a given claim is true or false (See Concerning Conversational Implicature, p. 17-23, for further considerations when assessing claims). Thus language learners need to be able to properly understand and use these connectives in order to be proficient in English.

In addition to the literature that has shown that these connectives are generally misunderstood by ELL's, Rader and Sloutsky (2001) found that we tend to remember claims that contain these connectives predictably poorly. Rader and Sloutsky (2001) forms the basis of the present thesis and so it is worth briefly describing what they did accomplished. Rader and Sloutsky (2001) tested native English speakers' ability to remember 'and', 'or', and 'if, then' claims and found the presence of what they termed conjunctive bias. This phenomenon is the tendency to recall 'and' claims more accurately than 'or' and 'if, then' claims, as well as the tendency to recall 'or' and 'if, then' claims as 'and' claims (Rader & Sloutsky, 2001, p. 838) (See Logical Connectives and Conjunctive Bias, p. 26, and Conjunctive Bias, p. 9, for more information). This bias shows that our comprehension of compound and complex claims is skewed in favour of representing these claims as though their main connective was 'and', which drastically changes the meaning and implications of these claims that we encounter on a day-to-day basis (See Logic, Reasoning, and Literacy, p. 5-9, for more information). Up to this date, the scientific literature has not assessed whether this bias is present in ELL's or whether there is a link between conjunctive bias and knowledge of truth functions. That is, whether improved knowledge of these connectives corresponds with improved memory of the claims that they form. Drawing upon the tools and methods of Rader and Sloutsky (2001) used to assess conjunctive bias, the literature surrounding ELL's, and the literature surrounding methods of instruction in formal and informal logic, this study will build upon the findings of Rader & Sloutsky (2001) and contribute to ELL and literacy research by assessing whether increased knowledge of truth-functional connectives reduces or eliminates conjunctive bias. Positive findings will show the importance of instruction in the truth functions of English connectives to achieve comprehension and proficiency in English.

The following thesis will: explain the role that t-f connectives have in our language; provide the theoretical motivation and base of this study; draw upon the current body of research to provide a background in this research area and review methods of best practice surrounding instruction; illustrate the void in the literature that this study intends to begin to fill; outline the research methods for the proposed study; provide the results of the analyses carried out on the data of test performance, and discuss the implications that may arise by addressing the primary research question: is an increase in knowledge of truth-functional connectives related to a decrease in conjunctive bias? In the pursuit of this primary question, the following thesis will also assess: the psychometric properties of instruments to assess conjunctive bias and knowledge of truth-functional connectives, the knowledge of truth-functional connectives among ELLs and their proficiency at assessing the truth or falsity of truth-functional claims, whether ELLs suffer from conjunctive bias, and the effectiveness of a new method of instruction to improve knowledge of truth-functional connectives.

To aid in the comprehension of this thesis the hypotheses will be referred to using the names following Table 1 below.

Table 1: List of Hypotheses

Hypothesis Name	Hypothesis
Hypothesis 1 (H1)	An increase in the knowledge of truth-functional connectives is related to a decrease in conjunctive bias.
Hypothesis 2 (H2)	Untrained ELL students will perform on the Test of Claim Evaluation as predicted by mental model theory.
Hypothesis 3 (H3)	Untrained ELL students will exhibit conjunctive bias - as predicted by performance on the Test of Claim Evaluation by Rader and Sloutsky (2001).
Hypothesis 4 (H4)	Untrained ELL students will show a poor understanding of truth-functional connectives.
Hypothesis 5 (H5)	Explicit instruction in truth-functions of English connectives is a significantly effective method of improving the understanding of truth-functions among ELL students.
Hypothesis 6 (H6)	Implicit instruction in truth-functions of English connectives is not a significantly effective method of improving the understanding of truth-functions among ELL students.
Hypothesis 7 (H7)	Explicit instruction in truth-functions of English connectives is significantly more effective than implicit instruction in English connectives.

1.1 Literacy

‘Literacy’ was a word initially only used to denote the ability to read and write. However, in the present day this word has taken on a wider meaning in that it is often used to refer to one’s ability to function in any given domain of meaning (Blair, 1990, p. 90). In the domain of computers, for example, an individual may be referred to as ‘computer literate’, where “computer literacy refers to the ability to function with

computers” (Blair, 1990, p. 70). It is important to note, that in this document the word ‘literacy’ is used only to refer to the former definition, i.e. to denote the ability to read and write.

1.2 Logic, Reasoning, and Literacy

Language and reasoning are the bedrock upon which we communicate with other individuals and truth-functional connectives are found throughout all of our language and reasoning. For this reason, it is surprising that truth-functional connectives have no place in our current curriculum.

The majority of sentences that we encounter and produce in academic text are claims. This is due to the fact that they are used to convey statements and information. The hallmark of claims is that they follow the principle of bivalence. That is, each and every claim is either true or false, but not both. There have been objections and problems raised to this claim. As raised in *How We Reason* (2006), Johnson-Laird discusses Bertrand Russell’s famous claim, “The present king of France is bald” (p. 233). This claim is used to address sentences where the presupposition (that there is a king of France) is false. Since there is no king of France one may be tempted to say that the claim is false. But, that would imply its negation – the statement “The present king of France isn’t bald” – is true. However, there is no present King of France. As noted by Johnson-Laird (2006), when sentences, such as the above, presuppose something that is false, “then neither the sentences nor their negations express propositions. They are neither true nor false. [...] The sentences fail to have a truth value, just as division by zero fails to yield a result” (p.233).

By using connectives we can connect simple claims (also known as atomic sentences), such as “The sky is blue”, to create more nuanced compound or complex

claims, such as “The sky is blue and it is sunny today”. *Within* its structure the compound claim reflects the relations of those claims it joins. These connectives are used by children, academics and everyone in-between on a daily basis, yet the term ‘truth-functional’ is completely absent from the vocabulary of the majority of those in the world. For a connective such as ‘or’, ‘and’, ‘if...then’, and ‘if and only if’ to be truth-functional it means that the compound or complex claim that it forms when used to join multiple claims will be true or false based upon the truth or falsity of the claims it joined. For example, ‘and’ and ‘or’ are both truth-functional connectives that have different truth-values, i.e. they work in different ways. The statement “Ford never saw the video or it doesn’t exist” means that Ford never saw the video, it doesn’t exist, or both and so, as long as both aren’t false – the claim is true. Whereas the statement “Ford never saw the video and it doesn’t exist” is only true if the video doesn’t exist *and* he never saw it. If one or both is false, then the statement is false. This may seem extremely obvious, but these claims, their nuances, and their implications often go by unnoticed. Furthermore, there are other t-f connectives, such as ‘if-then’ and ‘if and only if’, which have less intuitive rules than ‘and’ and ‘or’.

In what follows I will briefly outline the different truth-functions of these connectives –as we will be making references to them and their functions throughout this thesis. Before getting into the function of the connectives, it is important to note that in this thesis, unless specified otherwise, each connective will be treated as joining two atomic claims. We can represent these claims using two variables, such as ‘P’ and ‘Q’, and each of these variables can be assigned a truth-value of either “true” or “false”. Because of this, for each truth functional connective there will be four possible combinations. If we let ‘P’ and ‘Q’ represent each atomic claim as true, respectfully, and ‘-P’ and ‘-Q’ represent each atomic claim as false, respectively, the four combinations will look like this:

- (1) P Q
- (2) P -Q
- (3) -P Q
- (4) -P -Q

As can be seen these four combinations present an exhaustive account of the possible truth value combinations of proposition 'A' and 'B'. Each truth-functional connective varies as to which of these combinations will make the claim true or false.

In this thesis we will be discussing the conjunction 'and', inclusive disjunction 'or', exclusive disjunction 'or' (which will be represented by 'xor' from now on), conditional 'if, then', and the bi-conditional 'if and only if'. Using the same format as the above representation of truth value combinations, the truth-function of each of these truth-functional connectives is depicted in Table 2 below. Each combination of truth-values for the propositions will be labeled with 'TRUE' or 'FALSE' to its right hand side and underneath the given claim (column header). The four different values in each column cumulatively provide the truth-function of the given connective – showing us under what circumstances we should evaluate the given claim as true or false.

Table 2: Truth Functions of English Language Connectives

Truth Value of Proposition P and Q	Truth-Functional Connective				
	P and Q	P or Q	P xor Q	if P, then Q	P if and only if Q
P Q	TRUE	TRUE	FALSE	TRUE	TRUE
P -Q	FALSE	TRUE	TRUE	FALSE	FALSE
-P Q	FALSE	TRUE	TRUE	TRUE*	FALSE
-P -Q	FALSE	FALSE	FALSE	TRUE*	TRUE

As shown in Table 2, we can find the truth-function for the conjunction 'and' by looking at the first column of the truth-functional connectives. There is only one cell in the column under "P and Q" that is labelled "TRUE" and it is on the row that "P" and "Q" are listed as true. Therefore, we know that 'and' claims are only true when all their conjuncts - the claims joined by a conjunction - are true. In all other cases the conjunction is false. In the second column we can see that the inclusive disjunction 'or' is only false in the case where all its disjuncts - the claims joined by a disjunction - are false. In all other cases the disjunction is true. The exclusive disjunction 'xor' is very similar to 'or' except for the fact that it is not true in the case that both disjuncts are true. The conditional 'if, then' joins what is called an antecedent ('P') to a consequent ('Q'). As shown in Table 2, the only time that the conditional is false is when the antecedent is true and the consequent is false. The interesting trait of a conditional is that it only concerns what happens when the antecedent is true. Thus, in the case that the antecedent is false, the conditional cannot be falsified. This means that, due to the principle of bivalence, if

the conditional's antecedent is false, then the conditional is vacuously true. That is, it is true no matter the truth-value of the consequent. Lastly, the biconditional 'if and only if' is true in the case where both of the claims it joins are true – and in the case where they are both false. In the latter, neither of the two conditions that the claim is evaluated for are present. Thus, the biconditional cannot be falsified in this instance. Just as is the case with the conditional, due to the principle of bivalence we evaluate the claim as true.

As this section shows, t-f connectives show the relationships between claims within compound and complex claims, and our language is saturated with these logical relations. So, why is elementary logic not included in educational instruction and specifically, literacy strategies and instruction? There are three significant reasons why this may be the case. Firstly, logic is seen as too abstract a discipline to be effectively applied to everyday tasks such as reading and writing, i.e., it seems unlikely that knowledge of logic would transfer to these tasks. Secondly, largely due to its abstract nature, even if it is applicable it seems unlikely that these rules would be internalized and thus applied over the long-term. Thirdly, natural language may not be seen as truth-functional (see Literature Review, p. 17-23, for further discussion). The literature review will address these issues and give further background on this topic by drawing upon relevant and pertinent literature that reports on studies from the mid 50's to 2013.

1.3 Conjunctive Bias

Conjunctive bias is the tendency that individuals have: (1) to recall conjunctive claims ('and') claims with more accuracy than disjunctive ('or'/'xor') and conditional ('if...then') claims and (2) to recall disjunctive and conditional claims *as* conjuncts (Rader & Sloutsky, 2001). The discovery of this bias by Rader and Sloutsky (2001) shows that claims such as the disjunct: "Ford never saw the video or it doesn't exist" are

regularly misinterpreted to be “Ford never saw the video and it doesn’t exist” – which is a much stronger claim. The former would be true in the case that:

- a) Ford never saw the video; The video exists
- b) Ford saw the video; The video doesn’t exist
- c) Ford never saw the video; The video doesn’t exist

Whereas the latter claim would only be true if option ‘c’ were true, i.e., Ford never saw the video and it doesn’t exist, which could be true if Ford saw the video and then it was destroyed. The evidence that we hold this bias shows we tend to exclude viable possibilities (such as options ‘a’ and ‘b’ above) from our understanding of compound claims. Note that ‘b’ could be true in the case that Ford saw the video and then destroyed it. The explanation for this bias draws upon mental model theory, suggesting that when remembering claims individuals “tend to represent only the conjunction of a proposition’s atomic constituents” (Rader & Sloutsky, 2001, p. 846). That is, regardless as to whether the claim encountered is a conjunction, disjunction, or conditional the atomic claims that are held within the claim are represented in a mental model as a conjunction. Thus, as explained by Rader & Sloutsky (2001), “if presented with a memory task, conjunctions, which are compatible with one possibility, should be remembered more accurately than other propositional forms, such as disjunctions and conditionals, which are compatible with multiple possibilities, and disjunctions and conditionals tend to be converted to conjunctions” (p. 846). In addition, work by Goodwin and Johnson-Laird (2011) shows that the greater the number of possibilities to be represented the more difficult the concept is to learn (p.50). These complex and compound claims make up a substantial amount of our written and spoken discourse in political, academic, and social realms, and thus the presence of this bias has significant implications for both accurate comprehension and proper usage of language. Hence, conjunctive bias is an important subject in the discussion of ELL proficiency. By

measuring conjunctive bias before and after the instruction of the truth-functions of claims, this study will be able to assess the potential effect of instruction in- and knowledge of- truth-functional connectives on conjunctive bias. Thus providing a reliable assessment of memory and comprehension of compound and complex claims before and after instruction.

Chapter 2 : Theoretical Framework

2 Theoretical Framework

The theoretical framework is composed of two elements: critical theory and positivism. Critical theory provides the theoretical basis of motivation for this study and rationale as to the societal issues which this dissertation aims to begin to address. Positivism provides the scientific method by which this dissertation is carried out – providing the means to relate to the knowledge based and psychological properties that it aims to address. The following section will present these two theories and their relation to this dissertation.

The theoretical basis of motivation for this study is set in critical theory and has an emancipatory interest. That is, this study is motivated by a concern with “praxis – action that is informed by reflection with the aim to emancipate” (Cohen, Manion & Morrison, 2011, p. 32). The author holds the view that by excluding truth-functions, logical form, and fallacies in reasoning from core curriculum, learners will lack the instruction to ensure they become strong and critical thinkers who are highly proficient in language. Although many curricula, such as the Ontario elementary curriculum, now include requirements for critical thinking they lack the explicit instruction in these forms. Without explicit instruction in these skills we risk producing learners who – when confronted with arguments and complex claims – will have difficulty separating the wheat from the chaff. As put by Hyslop-Margison and Pinto (2007), we may produce learners who “adopt a more passive role by simply ‘receiving and comprehending ideas and information.’ Without a strong grasp of how the language conveys logical relations, ELL’s may not accurately comprehend ideas that involve logical relations in addition to lacking the skills necessary to understand and critically evaluate the information they are provided. Hence, the role of learner [may] become a politically compliant or passive one

where they assimilate the textual messages provided by some external source or authority” (p. 197).

The skills being investigated in this study form an essential component of the fundamental skills necessary to become an individual critically and truly democratically engaged in their environment. As said by Dam and Volman (2004), “if education is to further the critical competence of students, it must provide them with the opportunity at the level of the classroom and the school to observe, imitate and practice critical agency and to reflect upon it” (AB). Positive findings in the proposed study will show the effect that receiving explicit instruction in logical connectives has on our ability to accurately assess the truth or falsity of compound and complex claims and whether truth-functional knowledge of these claims has an effect on conjunctive bias. These skills are necessary to effectively evaluate the strength of arguments containing complex and compound claims. The ability to implement these skills is fundamental in moving from a role in which one is politically and ideologically passive to a more politically and ideologically active role. It is at this point that we rely upon the theoretical framework of positivism to bolster the methodology that will be used to carry out the research questions.

The procedures that this study follows are based in positivism. Although conventionally at odds with critical theory, positivism provides the means by which to effectively measure the knowledge and outcomes predicted by the hypotheses in this experiment. By creating and validating quantitatively evaluative tools this study has been able to set measureable hypotheses using the scientific method. This method and the instruments used will allow a quantitative comparison with research in the area of education, logic, critical thinking, conjunctive bias, and mental model theory.

Chapter 3 : Literature Review

3 Literature Review

This section will provide a brief of a systematic review of the literature, including several meta-analyses which expand the coverage of this review to include studies from the mid 50's to 2013. Due to the close tie between instruction in formal and informal logic and critical thinking (CT) interventions, the outset of the review will discuss the literature covering the relation of CT and literacy; trends in the research surrounding CT instruction (Abrami, Bernard, & Borokhovski et al., 2008); and findings that support instruction in logical connectives for the development of CT (McCarthy-Tucker, 1995). Following the review of literature surrounding CT will be a review of the relation of Grice's (1975) influential work on conversational implicature and truth-functional connectives. We will then review the relation of truth-functional connectives and mental model theory (Goodwin & Johnson-Laird, 2011), conjunctive bias (Rader & Sloutsky, 2001), and comprehension of logical connectives and ELL's (Bolton et al., 2002; Chaudron & Richards, 1986; Chung, 2000; Chen, 2006; Goldman & Murray, 1992; Jung, 2003, 2006; Haberlandt, 1982; Hinkel, 2002; Loman & Mayer, 1983; Millis & Just, 1994; Ozono, 2002; Ozono & Ito, 2003; Pretorius, 2006; Sanders & Noorman, 2000; Vasiljevic, 2013; Zhang, 2000). Lastly, research will be highlighted that shows how a technique known as contextual interference can further enhance long-term recall of basic logic as well as its transferability across tasks (Carlson & Yaure, 1990; Helsdingen, Gog, & Merrienboer, 2011).

3.1 Critical thinking

Critical thinking (CT) has been a significant topic of investigation for the past 60 years (Abrami, Bernard, Borokhovski et al., 2008). As opposed to literacy interventions -

instructional strategies and research under the title of ‘critical thinking’ have drawn upon the use of logic in instructional interventions. These interventions often focus on informal fallacies, assessing evidence, logical form, and group discussions that analyse different points of view and require students to look at their reasoning. Studies on ELLs have assessed the effect that the presence of English connectives has on comprehension. However, little to no work has been conducted using instructional interventions that focus on the effect that teaching the function of t-f connectives can have on reading ability. Most often, as is the case with many of the following studies, the interventions are typically assessed with CT measures such as the California Critical Thinking Skills Test or the Watson-Glaser Critical Thinking Test.

3.2 Critical thinking and literacy

Reading and writing are meaning making processes and as we read we are interpreting text. If we are doing it well, we are analysing it, evaluating it, making inferences, predicting, evaluating those predictions, and evaluating our understanding. These phenomenon are present in the process of hypothesis formation which studies have shown good readers are especially active in and has been integrated into strategies to aid in reading comprehension (Brunstein & Glaser, 2011; McKeown & Beck, 2009). The American Philosophical Association Delphi panel of 46 experts “identified six skills (interpretation, analysis, evaluation, inference, explanation, and self-regulation) associated with CT” (Abrami et al., 2008, p. 1103). Several of these skills are present in the methods that stem from hypothesis formation (Brunstein & Glaser, 2011; McKeown & Beck, 2009) and the first three (interpretation, analysis, and evaluation) are variables that the current study intends to measure and compare between individuals of varying proficiency in the English language who are given implicit or explicit instruction in t-f connectives. Due to the similarity in skills involved in CT research and the proposed

research it is assumed that the general findings from CT interventions will be applicable to the subject of literacy in the study being proposed. These findings will be applied to the instruction and exercises provided to participants

3.3 Trends in critical thinking studies

The following section investigates trends in CT-intervention studies. Included among the results is a meta-analysis of critical thinking instructional interventions conducted by Abrami et al. (2008). This meta-analysis included data from 117 studies which were all publicly available, addressed the issue of “CT development, improvement, and/or active use” (p.1108), included an instruction intervention that lasted at least 3 hours in total, compared outcomes based on different instructional approaches or levels of treatment, used quantitative data that allowed analysis of effect size, and participants were 6 years of age or older (Abrami et al., 2008, p. 1108). The findings from the meta-analysis supported the first and third trends noted in the paragraph below.

The literature on CT-intervention studies shows three very clear trends. Firstly, interventions which involve implicit instruction consistently and significantly underperform those interventions that involve explicit instruction (Abrami et al., 2008; Bangert-Drowns & Bankert, 1990; Angeli & Valanides, 2008; Hunt, 2002). As highlighted by Angeli and Valanides (2008), teachers must be explicit about the intended outcomes and in their instruction of them, i.e., instructors can't merely say CT will be covered or simply deal with difficult issues and expect students to show improvements in CT - they must set explicit goals and give students explicit instruction in the given strategies (p. 332). Secondly, although studies in this area are limited, it has been shown in multiple intervention-based studies that instruction in formal logic increases CT ability (Annis & Annis, 1979; McCarthy-Tucker, 1995). In a study by McCarthy-Tucker (1995), the hypothesis that increased mastery of logical reasoning would result in increased

performance on standardized measures of CT was *strongly* supported (p. 114). Lastly, in comparison studies of instructional approaches to develop CT skills it was found that in addition to the explicit instruction in CT skills, those who had been instructed explicitly in these skills and then were shown how to apply skills to course content showed the greatest increases in performance (compared with: control groups; those given explicit instruction only in CT skills and principles; and those instructed in CT procedures, such as a group discussion, with no explicit teaching of general CT skills and principles) (Abrami et al., 2008; Angeli & Valanides, 2009). Based on the assumption that these findings would apply to instruction intended to assess critical literacy, it is suggested that explicit instruction is needed, that formal logic instruction will have an effect on the dependent variables, and that interventions with the greatest effect will involve a mix of explicit instruction of principles followed by instruction on how to apply those principles to the domain of interest.

Research by Klein, Olson, and Stanovich (1997), provided initial support for the hypothesis that explicit instruction in logical form followed by instruction in application of this knowledge to reading “significantly affected students’ argument evaluation” (p. 45). Klein, Olson, and Stanovich’s (1997) study was different in the area of logical instruction (logical form rather than logical connectives), but provides a foothold for the further use of instruction in logic to positively affect students literacy skills.

3.4 Concerning conversational implicature

Coined by Grice (1975), conversational implicature, broadly speaking, refers to the different ways in which a given sentence may be reasonably interpreted. Given the impact of Grice’s work and the close relationship of assessing truth-functional claims and the interpretation of sentences, a discussion of the relation of conversational implicature and truth-functional connectives is due. In the following section, I will briefly review the

aspects of conversational implicature most pertinent to our discussion and the relation between these and truth-functional connectives. Then I will outline the shortcomings of strictly truth-functional knowledge when applied to the understanding of conversational implicature and conclude by highlighting the value of a robust understanding of truth-functional connectives when navigating conversational implicature.

Firstly, it is important to understand the function and consequences of conversational implicature. Conversational implicature focuses on the distinctions between “what is said, what is conventionally implicated, and what is nonconventionally implicated” (Grice, 1991, p. 41) and the rules surrounding those distinctions - when one makes a claim, or to use Grice’s more general term, utterance (Note: Although our discussion is focused on claims, i.e., sentences that are true or false, but not both – Grice’s term “utterance” and discussion of conversational implicature refers to a wide range of sentences more broad than claims, such as questions or commands which can be used to convey multiple meanings. However, as noted above, our discussion will be limited to the relation of truth-functional connectives and conversational implicature). We do not have to look very far to find a case of this occurring in relation to truth-functional connectives. For example, take the truth-functional connective ‘or’, which can be understood as an inclusive or exclusive disjunction. The breakfast menu at a restaurant or diner typically includes the claim that coffee *or* tea is included with the purchase of a breakfast. What is conventionally implicated has the function of an exclusive disjunction, i.e., with the purchase of a breakfast you may have either a coffee or a tea, but not both. Whereas, the nonconventional implication is that of a disjunction, i.e., with the purchase of a breakfast you may have a coffee, tea, or both. Most speakers, listeners, and readers understand that the second, nonconventional interpretation, is not the intended meaning of the menu. This understanding – rather than stemming from the exhaustive knowledge of the truth-functions of ‘or’ – comes from an understanding of the conventions in the

context and culture that the claim is made in. These conventions are the foundation of conversational implicature and it seems clear that one's language proficiency is strongly affected by one's understanding of these implicatures in a given language.

Truth-functional connectives, as noted in the above section Logic, Reasoning, and Literacy (p. 5), have specific interpretations. Aside from the question as to whether a disjunctive ('or') claim is intended as inclusive or exclusive there is no question as to what circumstances will make a truth-functional claim true or false. Although logicians have contested whether natural language connectives such as 'and', 'or', 'if', and 'if and only if' diverge from their formal Boolean counterparts, Grice (1975) maintains that "the common assumption [...] that the divergences do in fact exist is (broadly speaking) a common mistake, and that the mistake arises from an inadequate attention to the nature and importance of the conditions governing conversation" (Grice, 1975, p.41).

In Grice's *Logic and Conversation* (1975) he outlines the various conventions governing conversation through general principles and maxims, and thus outlines the rules of conversational implicature. These principles and maxims all stem from what Grice calls the Cooperative Principle, which states that when engaging in communication the aim is to make your "contribution such as is required, at the stage at which it occurs, by the accepted purpose or direction of the talk exchange in which you are engaged" (Grice, 1975, p.46). Simply put, the Cooperative Principle claims that we should be aware of the purpose and intents in the conversation we are engaged in and make contributions to that conversation that are in line with- and relevant to- that purpose. An example of one of these is his supermaxim, under Grice's category of Manner, "Be perspicuous" (Grice, 1975, p. 46). That is, as defined by Merriam-Webster Dictionary, to be "plain to the understanding especially because of clarity and precision of presentation". So, for example, if a restaurant intended to include the option of both a free

coffee *and* tea being available, they would go so far as to say “coffee *and* tea is included with purchase of a breakfast” or “coffee, tea, or both are included with purchase of a breakfast”. According to Grice’s rules of conversational implicature, when speaking or writing we ought to be as specific as we can be – without being overly verbose (Grice, 1975, p. 45) in an attempt to ensure we clearly convey accurate information.

In our communication, the rules of Grice’s conversational implicature are often followed. So, it is generally safe to assume that an ‘or’ claim is intended as an exclusive disjunction unless it is categorically impossible, e.g., “The table is a circle or square” or is accompanied by a clarifying claim such as “all of the above” as the last disjunct in an ‘or’ claim. E.g., “We can go to the park, go out for a movie, get ice cream, or all of the above”. In summary, Grice’s conversational implicature outlines the principles, founded on the Cooperative Principle, that act as a framework to facilitate the clear understanding of claims.

Grice’s principles, however useful when navigating conversation, are not natural laws and speakers do not always follow the rules of conversational implicature. Sometimes speakers will deliberately violate these rules to mislead the hearer – saying something that is conventionally interpreted one way and knowingly omitting details that would lead to a correct interpretation. When this happens Grice says that “a maxim is being exploited” (Grice, 1975, p.49). Similar to the above examples an ‘or’ claim can be exploited to form an answer to a question when the speaker knows that only one of the disjuncts is true (and thus could avoid using a disjunction altogether) – or knows that both of the disjuncts are true (and thus could use a conjunction). Both of these cases are examples of the speaker making an utterance that is intentionally and unnecessarily ambiguous. This intentional misuse of truth-functional connectives can be classified as exploiting Grice’s maxim of ambiguity which falls under the supermaxim ‘be

perspicuous' by intentionally making a claim with multiple interpretations as well as exploiting the related maxim 'be brief' (Grice, 1975, p.46), which specifies that we should avoid unnecessary length. Both of these maxims fall under Grice's category of Manner mentioned above and can be easily exploited through the use of the truth-functional connectives 'or' – as noted above - and 'if, then'. The ways that the truth-functional connectives can be exploited is discussed below.

A claim classified as a conjunction, that is, with 'and' as its main truth-functional connective cannot be used in this way. A *negation* of a conjunction can. By adding on unnecessary conjuncts to the negated conjunction – one can obscure the meaning of the claim. For example, if we have two individuals, A and B – if A doesn't ride horses then the negation "It is not the case that A and B ride horses" is true – even if B rides horses. However, as mentioned above this is not a conjunction, but a negation. Furthermore, using De Morgan's equivalence this claim can be translated to the disjunct "A doesn't ride horses or B doesn't ride horses". Noting that it is a disjunction, we can follow the same reasoning as the above paragraph to show how this claim exploits the rules of conversational implicature.

A claim classified as a conditional, that is, with 'if, then' as its main truth-functional connective can be used to exploit the rules of conversational implicature (Note: For the purposes of this study we will only be using conditional examples that follow the form 'if, then' – although there are other natural language conditionals, such as 'unless', 'if, 'then', and 'only if'). This is in virtue of the fact that a conditional is a claim that speaks of what will occur if the antecedent of the conditional claim is true – and *not* what will happen if the antecedent is false. For example, a father may say "if you eat your vegetables, then you can have dessert" and the claim would not be false if the vegetables were not eaten and the father gave his child dessert. This is because the

antecedent “you eat your vegetables” sets the stage in the conditional as to what will happen if it is true, but not what will happen if it is false. So the speaker has not bound themselves to any commitment regarding the case when the antecedent is false. This shows us that truth-functionally the only time this claim is proven false is when the antecedent “you eat your vegetables” is true and the consequent “you can have dessert” is false. However, as noted in the second paragraph of this subsection, conversational implicature deals with “what is said, what is conventionally implicated, and what is nonconventionally implicated” (41, Grice, 1991, *Studies In the Way of Words*). In the case of the conditional ‘if, then’ statement given above, it is conventionally implicated that the claim is in fact a bi-conditional. That is, the father implies the conventional interpretation “you can have dessert if and only if you finish your vegetables”. It is because of this common divergence in conventional and nonconventional interpretation that we find speakers are able to exploit the conditional ‘if, then’ to mislead the hearer.

The bi-conditional ‘if and only if’ cannot be exploited in the same ways as the other connectives due to its straightforward nature. It is understood strictly by the conventional interpretation – lacking the nonconventional interpretation of the other connectives and thus, it lacks the discrepancies in understanding that arose in the cases discussed above.

Through the above examples it has been shown that negated conjunctions, disjunctions, and conditional claims can all be exploited by speakers to mislead and deceive hearers. This exploitation arises from the ability to use the connectives that form these claims in ambiguous and unnecessarily long-winded ways. The ability to understand whether the intention of the speaker is to mislead and deceive or be clear and straightforward is a skill that is extraneous to this study. However, as shown from the discussion above, by understanding the truth-functions of these connectives we can come

to a full understanding of the conventional and nonconventional interpretations of these claims. It should be noted that this is a skill that may be able to be applied to reduce the effectiveness of exploitation in conversational implicature. However, whether or not truth-functional knowledge can aid in the recognition of exploitation in conversational implicature is a question and discussion that is beyond the scope of this study (See Recommendations for Future Research for further discussion). We have, in our discussion of conversational implicature, shown the relationship of truth-functional connectives and conversational implicature as well as exemplified the claim by Grice that “the common assumption [...] that the divergences [between Boolean connectives and their natural language counterparts] do in fact exist is (broadly speaking) a common mistake, and that the mistake arises from an inadequate attention to the nature and importance of the conditions governing conversation” (Grice, 1975, p.41).

3.5 Logical connectives and mental model theory

Truth-functional connectives join propositions to create compound and complex claims that are either true or false (Goodwin & Johnson-Laird, 2001, p.42). The theory of mental models – or model theory – provides an account of how individuals represent these truth-functional expressions. As the name implies the model theory suggests that individuals create mental models of the situations in which these truth-functional expressions are true. The model theory relies upon three main assumptions which are outlined in Johnson-Laird (2001, p. 435):

- (1) Each mental model represents a possibility
- (2) The principle of truth: mental models represent what is true [...], but by default not what is false.
- (3) Deductive reasoning depends on mental models.

It is important to note that the second assumption has an exception that can overrule the principle of truth. That is, “individuals make ‘mental footnotes’ about the falsity of clauses, and if they retain the footnotes they can flesh out *mental* models into *fully explicit* models, which represent clauses even when they are false” (Johnson-Laird, 2001, p.435). The present study intends to exploit the exception of the second rule in an effort to build the competence of English Language Learners knowledge of truth-functional connectives. Furthermore, the model theory will be used to validate the instrument this study uses to assess knowledge of truth-functional claims. This is due to the fact that “mental model theory predicts that the number of models for a concept should predict its difficulty” (Goodwin & Johnson-Laird, 2011, p.50). That is, the more variations that a concept or claim has that make it true, the more difficult it is to learn.

Model theory suggests that mental models represent true possibilities for the given concept or claim. In relation to truth-functional connectives, this means that the number of models required to represent the given claim is the same as the number of instances that the given claim is true in each of the total possibilities of truth-value combinations of the propositions that the connective joins. Thus, we can determine the number of models needed for each connective by enumerating the number of ‘TRUE’ instances in its respective column in Table 2. This shows us that: ‘and’ requires one mental model, ‘xor’ and ‘if and only if’ require two mental models, and ‘or’ and ‘if, then’ require three mental models.

Prediction of number of mental models needed to represent a concept or claim predicts the difficulty of that concept or claim (Goodwin & Johnson-Laird, 2011, p.50). Furthermore, “Naïve reasoners, as Osherson (1974-1976) argued, do not rely on truth tables. According to the model theory, they rely instead on a representation that captures the possibilities consistent with an assertion’s truth” (Goodwin & Johnson-Laird, 2011, p.

42). Thus, we can use mental model theory to predict the difficulty that individuals unfamiliar with the subtleties of English connectives, such as ELL's, will have interpreting truth-functional connectives. Given this knowledge, we can expect that the truth-functional connective 'and' will be the easiest to understand, followed by 'xor' and 'if and only if', which in turn are followed by 'or' and 'if, then'. Building an understanding of the connectives that ELL students have the most difficulty with can be used to inform pedagogy in the ELL classroom to ensure that students are provided with the instruction needed to ensure they leave their classes with high comprehension and proficiency in English.

This prediction can be modified by the principle of *simplifying* models presented by Goodwin & Johnson-Laird (2011). This principle states that “when individuals acquire a Boolean concept from its instances they represent its instance and can reduce the load on memory by eliminating those variables that are irrelevant given the values of the other variables” (Goodwin & Johnson-Laird, 2011, p. 44). For example, in the conditional ‘if, then’ statement where the instance of the antecedent is false – the truth-value of the consequent can be disregarded because we know that the statement is vacuously true. Furthermore, “individuals can represent the set of non-instances instead of the set of instances, particularly when the number of instances exceed the number of non-instances” (Goodwin & Johnson-Laird, 2011, p. 44). Such as the inclusive disjunction ‘or’, the number of non-instances (cases where the claim is false) is one and thus, the load on working memory can be greatly reduced by using models to represent the single non-instance – rather than the three instances that it is true. By decreasing the load on working memory, individuals have greater processing power and thus performance in their comprehension and proficiency in English is likely to increase (Goodwin & Johnson-Laird, 2011, p. 46). The principle of making models of non-instances can also be applied to the conditional ‘if, then’ reducing the number of models necessary to represent this

claim down to one as well. Thus, when individuals are proficient in the use and evaluation of truth-functional connectives and can learn to represent claims with fewer mental models, we can expect the performance differences between connectives to be significantly reduced.

3.6 Logical connectives and conjunctive bias

As noted in the above section Conjunctive Bias (p. 9-11), conjunctive bias is the tendency that individuals have: (1) to recall conjunctive claims ('and') claims with more accuracy than disjunctive ('or') and conditional ('if...then') claims and (2) to recall disjunctive and conditional claims *as* conjuncts (Rader & Sloutsky, 2001). This bias was discovered by Rader and Sloutsky (2001) who assessed the presence of conjunctive bias among 29 undergraduate university students. Rader and Sloutsky (2001) assessed conjunctive bias by using an old/new recognition procedure where participants were asked to remember a set of conjunctions, disjunctions, and conditionals – being given 10 seconds per statement (Rader & Sloutsky, 2001, p.842). In the recognition procedure they were given the same 'target' statements mixed in with a group of similar 'foil' statements ("different-form foils") that varied from the target statements in the logical connectives used ('and', 'or', and 'if, then'). Also included in the recognition phase were foil statements that varied from the target by using a "non-logical" connective "in that these connectives are not the basic connectives of formal propositional logic but are considered natural-language equivalents of these connectives" (Rader & Sloutsky, 2001, p. 842). These "different-connective foils" used the non-logical connectives 'but', 'unless', and 'whenever'. Lastly, foil statements that had a different noun than the target statement were also used in the recognition phase.

As noted by Rader and Sloutsky (2001), "the different-noun and different-connective foils were included primarily as checks on random responding" (p. 842).

These foils either significantly changed the meaning of the statement through the change of the noun or used a connective that hadn't been included in the original list. Thus, Rader and Sloutsky (2001) had good reason to use these as easily identifiable controls for random responding. In contrast, the target statements and different-form foils only changed the connective used in the statement. These were of "primary interest because the [conjunctive bias] hypotheses concern participants' abilities to discriminate the targets of each propositional form from these distractors [foils]" (Rader & Sloutsky, 2001, p. 842). Rader and Sloutsky (2001) were looking to see if target conjuncts were accepted more frequently than target disjuncts and conditionals. They were also looking to see if there was a tendency for 'or' and 'if, then' original statements to be incorrectly identified as conjunction foils. Figure 1 below shows the results of this study. As can be shown across the original disjunction and conditional forms, the conjunction foil had a tendency to be accepted approximately 50% of the time as the original form in both cases. Furthermore, although recall of the respective target connectives is improved relative to the performance of the foils in the respective original forms – the only target connective that significantly outperforms both foils is the conjunction. Thus, Rader and Sloutsky (2001) were successful in identifying the novel phenomenon of conjunctive bias in memory (p. 838).

This bias show that we have a tendency toward a skewed memory of compound and complex claims. For the purposes of this thesis it is important to note the link between memory and comprehension, by using the Test of Conjunctive Bias to assess participants' memory of claims we indirectly assess their interpretation of the claims. This measure shows whether respondents have accurate comprehension and memory of claims and/or whether they have a predictable tendency to incorrectly interpret claims, which reflects upon proficiency in English. As shown by Rader and Sloutsky (2001), English speakers do show a tendency to misrepresent these claims – signifying problems

in comprehension and proficiency in English. Thus, if this study shows that instruction in truth functions reduces or eliminates this conjunctive bias, we can conclude that instruction in truth functions increases accurate comprehension and proficiency of English.

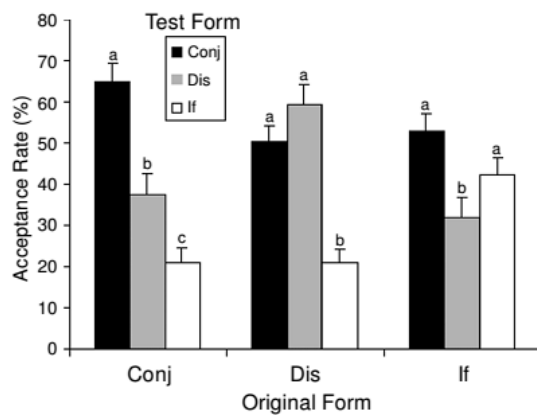


Figure 2. Mean acceptance rates (+SE) by original propositional form and test propositional form, Experiment 2. Within each original form, means that do not share letters differ at $p < .01$ in Bonferroni-adjusted contrasts.

Figure 1: Rader and Sloutsky's (2001) presentation of conjunctive bias (p. 845)

3.7 Logical connectives, comprehension, and English Language Learners

ELL's are consistently found to overuse, misunderstand, and misuse connectives in the English language (Bolton et al., 2002; Chen, 2006; Hinkel, 2002; Ozono & Ito, 2003; Zhang, 2000). Empirical research has shown that when compared to implicit logical relations the presence of explicit logical relations increased the following: text comprehension (Chung, 2000; Goldman & Murray, 1992; Loman & Mayer, 1983; Ozono, 2002; Vasiljevic, 2013); listening comprehension (Chaudron & Richards, 1986;

Jung, 2003, 2006); and speed of text processing (Haberlandt, 1982; Millis & Just, 1994; Sanders & Noorman, 2000). Research has also shown that participants with different proficiency levels vary significantly in their comprehension of logical connectives (Chung, 2000; Ozono, 2002; Ozono & Ito, 2003) and that this difference in ELL's maps on to the developmental pattern seen for acquiring connectives (Pretorius, 2006). This research clearly exhibits the effect that the presence of logical connectives has and the interaction between proficiency in English and comprehension. The current study intends to contribute to this body of knowledge by focusing on the effects that instruction in these connectives may have and whether those effects are affected by proficiency levels in English.

3.8 Transferring skills across domains

Support for the generalizability of the knowledge of t-f connectives to other tasks comes from work by Carlson and Yaure (1990) who experimented with the effects of contextual interference. Contextual interference is a technique used when learning a task, such that practice materials (say, a sheet of mathematical problems) are presented in a mixed fashion (e.g., questions of multiplication, addition, division, etc... are presented in random order rather than section by section). The most strongly supported explanation for the positive effect that contextual interference has on learning is provided by the elaborative-processing hypothesis (Helsdingen et al., 2011, p. 384-385). The elaborative-processing hypothesis claims that when individuals are presented materials in random order they are forced to compare and contrast different tasks and thus, become more skilled at identifying the relevant features due to "more elaborate and distinctive memorial representations of the practiced tasks" (Helsdingen et al., 2011, p. 384). Using contextual interference as a method of practice during and after instruction in t-f connectives the "transfer of [these] component skills to problem solving" (Carlson &

Yaure, 1990, p. 490) was increased. Furthermore, when assessing the effects of contextual interference Helsdingen et al. (2011) showed that contextual interference results in greater long-term recall of the given skill, and that performance and transfer effects to tasks requiring complex judgment are increased through the use of retroactive prompts, i.e. feedback after the completion of a problem (Helsdingen et al., 2011, p. 390-391) (See Materials, p. 35-37, to see how these insights were applied to the exercises provided in the instruction).

3.9 Summary of the literature

In summary, the current body of literature shows us that knowledge of formal and informal logic can be transferred to and have a significant effect on language comprehension and production (Annis & Annis, 1979; Carlson & Yaure, 1990; Helsdingen et al., 2011; McCarthy-Tucker, 1995) and the evaluation of arguments (Klein et al., 1997). These findings are positively influenced by: *explicit* instruction in the given principles (Abrami et al., 2008; Angeli & Valanides, 2008; Bangert-Drowns & Bankert, 1990; Hunt, 2002); instruction in how to apply these principles to a given domain (Abrami et al., 2008; Angeli and Valanides, 2008); and by a practice schedule that involves contextual interference and retroactive prompts (Carlson & Yaure, 1990; Helsdingen et al., 2011). All of these major findings were integrated into the design of the instruction in this thesis in order to increase the probability that instruction in truth-functional connectives would result in retained knowledge of English connectives and the application of this knowledge in their comprehension and proficiency of English – as measured by the Test of Conjunctive Bias and the Test of Claim Evaluation (See Materials, p.38 and p. 35, for further information on these measures).

Additionally, conversational implicature, mental model theory, conjunctive bias, and ELL's knowledge of logical connectives were discussed. It was shown that

conversational implicature substantially effects the understanding and interpretation of truth-functional connectives in natural language (Grice, 1975; Grice, 1989). The relation of truth-functional connectives and mental model theory highlighted the predictive value of mental model theory when assessing truth-functional connectives (Goodwin & Johnson-Laird, 2011). The phenomenon of conjunctive bias is the tendency that individuals have to recall 'and' claims better than 'or' and 'if, then' claims as well as the tendency to recall 'or' and 'if, then' claims as 'and' claims (Rader & Sloutsky, 2001). The literature surrounding ELL's comprehension of truth-functional connectives showed that ELL's often misunderstand, misinterpret, and misuse logical connectives (Bolton et al., 2002; Chaudron & Richards, 1986; Chung, 2000; Chen, 2006; Goldman & Murray, 1992; Jung, 2003, 2006; Haberlandt, 1982; Hinkel, 2002; Loman & Mayer, 1983; Millis & Just, 1994; Ozono, 2002; Ozono & Ito, 2003; Pretorius, 2006; Sanders & Noorman, 2000; Vasiljevic, 2013; Zhang, 2000).

Chapter 4 : Methodology

4 Methodology

This experiment was broken up into five phases to accommodate the different assessments, methods of instruction, and steps required for a thorough and sound assessment of the research question: does increased proficiency in truth-functional connectives reduce conjunctive bias? The following methodology section will be split into five subsections to accommodate a clear explanation of the methods. For brevity, the materials and instructions used across the phases will only be explained in detail in the first phase that they are used. Changes in form of instrument will be noted. Note: Phase 4 and 5 are phases of analysis and do not involve new interventions. These phases use data collected across Phase 2 and 3. These were added to simplify the content of each phase (See Table 3 below for a breakdown of each phase, including what is assessed in each phase and which hypotheses each phase impacts; further information on these phases can be found below on page 40 and 41; see Table 4 below for a breakdown of the tests and instruction administered in each phase).

Table 3: Summary of Purpose and Pertinent Hypotheses for Each Phase.

Phase	Pertinent Hypotheses	Explanation
Phase 1A	H2	Validation of the Test of Claim Evaluation.
	H4	Assessment of ELL students' understanding of truth-functions.
Phase 1B	H3	Validation of the Test of Conjunctive Bias.
	H3	Assessment of whether ELL students have conjunctive bias.
Phase 2	H5, H6, H7	Comparison of the effect of implicit and explicit instruction of t-f connectives on t-f understanding.
Phase 3	H5, H6, H7	Assessment of the effect of explicit instruction of t-f connectives on the implicit instruction group of Phase 2.
Phase 4	H5, H6, H7	Assessment of whether there is a difference in t-f understanding between the explicit-instruction-only group and the group that received implicit and explicit instruction.
Phase 5	H1	Assessment of whether the instruction and corresponding increase in understanding of truth functions had an effect on conjunctive bias.

Table 4: Summary of Completed Tests and Instruction for Each Phase.

Phase	Completed Tests and Instruction
Phase 1A	Twenty-nine ELL students complete the Test of Claim Evaluation.
Phase 1B	Thirteen ELL students complete the Test of Conjunctive Bias
Phase 2	Twenty-five ELL students complete the Test of Conjunctive Bias Pretest Twenty-nine ELL students complete the Test of Claim Evaluation Pretest Seven ELL students complete implicit instruction in truth-functions Ten ELL students complete explicit instruction in truth-functions Seventeen ELL students complete the Test of Claim Evaluation Post-test
Phase 3	Seven ELL students who received implicit instruction in Phase 2 complete explicit instruction in truth-functions. Six ELL students complete the Test of Claim Evaluation Post-Test
Phase 4	No instruction or testing. Analysis phase comparing explicit post-test scores from Phase 2 with post-test scores of Phase 3
Phase 5	Nine ELL students complete the Test of Conjunctive Bias Post-test

4.1 Phase 1A

Due to the lack of data in the literature regarding ELL's proficiency in specific truth-functional connectives, Phase 1A assessed the validity of the Test of Claim Evaluation as well as ELL students understanding of the truth-functions of the conjunction 'and', the inclusive disjunction 'or', the exclusive disjunction 'or', the conditional 'if, then', and the bi-conditional 'if and only if'. These results inform H2 (Do untrained ELL students perform on the Test of Claim Evaluation as predicted by mental

model theory?) and H4 (Do untrained ELL students show a poor understanding of truth-functional connectives?), respectively.

4.1.1 *Participants*

Twenty-nine ELL's from an English program at a large western Ontario university voluntarily completed the experiment for extra feedback on their knowledge of English truth-functional connectives. The participants' proficiency in English ranged from intermediate ($n = 8$), through high-intermediate ($n = 4$), to advanced ($n = 17$). Participants in all phases of the study were recruited through an in-class presentation that described the role of connectives in the English language, the purpose of the study, and the expectations of participants.

4.1.2 *Materials*

The Test of Claim Evaluation is a 30 question multiple-choice test designed by Eric Smiley to evaluate participants' understanding of the truth functions of English connectives. The test was designed and refined over three years of experience teaching elementary and symbolic logic to undergraduate students at the University of Guelph. The test assesses participants on five different types of compound claims (in brackets is how the connective will appear in a sentence): conjunction ('...and...'), disjunction ('...or...'), exclusive disjunction ('...or...'), conditional ('if...then...'), and bi-conditional ('...if and only if...'). The test is made up of six questions of each type of claim and each set of six vary in complexity. Half of the questions on the test require the participants to select *each* option (full marks may require the selection of multiple options) that make the claim true while the other half require the participants to select *each* multiple choice option that makes the claim false. This method assesses a full understanding of the connective and by reversing the requirements of the questions

(making the claim true or false) the test ensures that the probability that a participants' score will vary due to chance is significantly reduced for two reasons (See Appendix A for a sample test item). Firstly, within a given connective, participants are tested on their understanding of the fully explicit model. Secondly, between given connectives participants must select the same number of options. So, they cannot simply deduce that there is one option when dealing with a conjunction and three when dealing with a condition. Importantly, by assessing students' knowledge of all possibilities that make a statement true or false, this test provides a comprehensive measure of comprehension and proficiency in the truth functions of English language connectives.

4.1.3 *Design and procedure*

The presentation of test items and recording of participant responses was carried out by the testing software Question Writer HTML5. The primary variables were English proficiency level (intermediate, high-intermediate, and advanced). The dependent variables were proficiency score for each language item ('and', 'or', 'xor', 'if, then', and 'if and only if'). All tests and instructional sessions were supervised/conducted by Eric Smiley.

Each participant was tested individually. At the beginning of the test participants were given a sample question that involved making the atomic claim "The tree is blue" true – and then were presented the same claim, but asked to make it false. The primary researcher aided participants if they did not have an understanding by explaining the procedure and then illustrating that with the second example. See below for an example of the sample question:

Select *each* answer that will make the following statement TRUE. Note: There may be multiple answers that make the statement true.

“The tree is blue”

- The tree is red
- The tree is green
- The tree is blue
- None of the above

The somewhat absurd atomic claim “The tree is blue” was chosen to illustrate that the test items were self-contained. That is, they did not need to reflect general statements about the world. An atomic claim was used as an example so that students would not have any practice effect for any of the particular compound or complex claims that would be assessed in the test. After this and a review of the same content when selecting the options that would make the claim false, the participant was asked if they had any questions. Participants were then told to begin the instruction, to take as much time as they needed, and to raise their hand if they had any questions regarding the test. Once all questions were addressed the participants were told to begin the test and reminded to pay attention to whether the question asked to make the claim true or false. To ensure no false responses, this reminder was given every four minutes during the test.

Upon beginning the test, each participant was presented with the following welcome screen:

Welcome to the Test of Claim Evaluation.

Each question will ask you to either make the main claim either true or false. Select EACH answer that will make the claim true (or false - depending on the question). Note: one question can have between 1 and 4 correct options. Select each one that would make the claim true (or false - depending on the question).

There is no time limit. When you click the next button the quiz will begin. Do your best to answer each question correctly. Good Luck!

Following the welcome screen participants then encountered the question items. Question items were presented individually. Participants were allowed to go back to an earlier question at any time during the test. Question order was randomly assigned for each participant by the Question Writer program.

4.2 Phase 1B

Due to the lack of data in the literature regarding conjunctive bias in ELL's, Phase 1B assessed a group of ELL's for conjunctive bias. The data from this phase was also used to validate the Test of Conjunctive Bias. The results of these measures informed H3: Do untrained ELL students exhibit conjunctive bias - as predicted by performance on the Test of Claim Evaluation by Rader and Sloutsky (2001)?

4.2.1 Participants

Twenty ELL's from an English program at a large western Ontario university voluntarily completed the experiment for feedback on their memory of English connectives. Seven of these participants were dropped from analysis because of acceptance rates of 40% or higher for the control items (different-noun and different-connective foils). It should be noted that some of these participants appeared very distracted – at times reaching for their phone mid-test – and others admitted that they “gave up” mid-test. Thus, the final sample included 13 participants that ranged between intermediate, high-intermediate, and advanced English proficiency.

4.2.2 *Materials*

The Test of Conjunctive Bias is a test designed to assess memory for conjunctions, disjunctions, and conditionals using an old/new recognition procedure. The original test created by Rader and Sloutsky (2001) is made of one section with two halves, the first half is made of an initial list of 45 propositions, also referred to as *original descriptions*, with 15 each in the forms of conjunction, disjunction, and conditional. Each proposition is a description of a hypothetical person and begins with: *This professor*. The second (recognition) portion is made of a list of 225 propositions. Included in the recognition portion are the 45 original descriptions, along with 180 foils; 4 foils are based on each original description. Following the form of Rader and Sloutsky (2001), there are two *different-form* foils for each of the other logical forms (e.g., a disjunctive target would have a conjunctive and conditional foil). The third foil, the *different-noun* foil, alters one noun in one atomic proposition from the original description. To ensure sensibility the noun changed “was changed into another one that was semantically sensible for that atomic proposition’s verb” (Rader & Sloutsky, 2001, p.842). The fourth foil, the *different-connective* foil, replaces the original connective with one that is non-logical – either ‘but’, ‘unless’, or ‘whenever’. As defined by Rader and Sloutsky (2001), the connective is “‘non-logical’ in that these connectives are not the basic connectives of formal propositional logic but are considered natural-language equivalents of these connectives” (p. 842). Following Rader and Sloutsky (2001), “each non-logical connective was used with five of the original descriptions of each propositional form, and assignment of these connectives to descriptions was random” (p. 842). That is, there is 15 *different-connective* ‘but’-statements – five for each original logical connective (‘and’, ‘or’, and ‘if, then’). The same holds true for the 15 *different-connective* ‘unless’-statements and the 15 *different-connective* ‘whenever’-statements.

In the current experiment a new form of the Test of Conjunctive Bias was created that differed from that used by Rader and Sloutsky (2001). This was completed to shorten the writing time of the test and reduce fatigue of participants. Preliminary tests showed that the performance of the full test was the same as the shortened version. The marked difference in the new form is in the reduction in the total number of test items and the breakup of the test into two sections. Between the two sections there are now 30 original descriptions (10 of each type of connective) rather than 45 (15 of each type of connective) and 120 foils (rather than 180). Totalling 150 items in the whole test (rather than 225). The two sections represent two old/new recognition procedures. This limited the number of original connectives (presented in the first half of each section) to be remembered for the recognition test to 15 (rather than 45). In the current Test of Conjunctive Bias for *each* five target descriptions there are an accompanying five different-noun foils, ten different form foils (five for each of the two non-original forms), two different-connective ‘but’ foils, two different-connective ‘unless’ foils, and one different-connective ‘whenever’ foil (See Appendix D for a section of the Test of Conjunctive Bias).

In summary, this version has the same internal logic and style of content as Rader and Sloutsky (2001). The changes made simply reduce the time to write the test and helped to ensure that fatigue does not confound the results.

4.2.3 *Design and procedure*

The presentation of item descriptions and recording of participants’ responses was controlled by a computer running the program SuperLab, Version 5.0 – an updated version of the program used by Rader and Sloutsky (2001) (p. 842). The primary variables, dependent measure, and definition of the acceptance rate, hit, and false alarm followed the specification outlined by Rader and Sloutsky (2001):

The primary variables, both manipulated within subjects, were the original form of the description (conjunction, disjunction, [and] conditional) and the test form of the description (conjunction, disjunction, [and] conditional). The dependent measure was the acceptance rate for test descriptions in each original–test combination. When the original and the test forms coincide, the test description is a target, and acceptance of it constitutes a hit. When the original form and the test form differ, the test description is a foil, and acceptance of it is a false alarm. Differences between hit and false alarm rates measure the ability to discriminate targets from different-form foils (p. 842).

In line with Rader and Sloutsky (2001), each participant was tested individually and instructed that they would be presented “a series of one-sentence descriptions of people, one at a time” (p. 842). Participants were also notified to “study the descriptions carefully, because memory for the descriptions would be tested after they all had been presented. The instructions also advised the participant not to be concerned if some of the descriptions seemed odd or unusual, but simply to study them carefully” (Rader & Sloutsky, 2001, p. 842). The test followed exactly the same procedure as Rader and Sloutsky (2001) (p.842):

Each description was presented by itself, centered, onscreen [computer screen]. The word READY appeared for 500 msec in the center of the screen to draw the participant’s attention. This cue disappeared, and the description [original description] appeared for 10 sec. The description [original description] then disappeared, and the process repeated for the next description. Order of presentation was randomized by the program for each participant.

After the last description was presented, another set of instructions appeared on screen. These instructions informed the participant that he or she would see

another series of descriptions [mix of original (now termed “target”) and foil statements], one at a time. For each description, the participant was to press the ‘Z’ key [for a target statement] if he or she believed that it had been presented previously [in the first set of ‘original statements’], and he or she was to press the ‘M’ key if he or she believed it to be new. The instructions state explicitly that the participant should only respond with *old* to descriptions that he or she believe match the original descriptions exactly, word for word. The participant was then instructed to place one finger each on the ‘Z’ and ‘M’ keys for the duration of the experiment. The participant then made old/new decisions for each of the test descriptions. The participant’s response to one description clears the screen and displays the next description. One description appears at a time, with each centered on screen. Order of presentation of test descriptions is randomized for each participant by the program.

4.3 Phase 2

This phase of the experiment was concerned with assessing the effects of implicit vs explicit instruction and exercises on proficiency in truth-functional connectives. The instruction and assessment of this phase informs H5: Is explicit instruction in truth-functions of English connectives a significantly effective method of improving the understanding of truth-functions among ELL students?; H6: Is implicit instruction in truth-functions of English connectives a significantly effective method of improving the understanding of truth-functions among ELL students?; and H7: Is explicit instruction in truth-functions of English connectives significantly more effective than implicit instruction in English connectives?

This phase employed a between and within groups pre-post- test experimental design. The between-groups variable is form of instruction (implicit or explicit) whereas

the within groups variable is understanding of truth-functional connectives ('and', 'or', 'xor', and 'if, then'). Due to limited instructional hours 'if and only if' was not assessed outside of Phase 1.

4.3.1 *Participants*

Twenty-nine ELL's from an English program at a large western Ontario university voluntarily completed the experiment for extra instruction and feedback on their understanding of truth-functional connectives in the English language. The participant's proficiency in English ranged between intermediate, high-intermediate, and advanced. Participants were matched for proficiency level and split into two groups, controlling for proficiency in English. The experiment took place near the end of the term for the participants and thus, several students dropped out to focus on their course work. Due to the attrition in the experiment the final sample consisted of 17 participants – seven in the implicit instruction group and ten in the explicit instruction group.

4.3.2 *Materials*

Two forms of the Test of Claim Evaluation were used in this experiment, one as a pre-test before instruction and the second as a post-test after instruction (See the Materials and Design and Procedure section in Phase 1A, p.35-37, for a full description of the Test of Claim Evaluation and the procedure followed when implementing it).

Exercises in claim evaluation were used to accompany instruction. These exercises mirrored the format of the Test of Claim Evaluation and were provided using Question Writer HTML5. These exercises differed from the Test of Claim Evaluation in the information provided with each question and by providing question-level feedback upon completion. Two sets of exercises were created for each type of instruction –

implicit or explicit instruction. With each question, the implicit exercises outlined the type of connective that was being presented. During feedback the implicit exercises highlighted which options were correct, provided a breakdown of the atomic claims that made up the compound or complex claim, and an accompanying general explanation (See Appendix B for an example). In contrast, with each question in the explicit exercises the type of connective *as well* as the truth-functional rules for the connective were presented. During feedback in the explicit exercises all the same information was provided as in the implicit exercises. In addition to the implicit exercise feedback, truth-functional explanations were given for why each option did or did not make the claim true or false (See Appendix B and C for a comparison of both instructional exercises and their feedback).

There are four sets of exercises that were created to accompany each day of instruction. In each set of exercises half of the items required the participant to make the given claim true and the other half required the participant to make the given claim false. The day one exercise was made of six inclusive disjunction questions. The day two exercise was made of six conditional questions. The day three exercise was made of six inclusive disjunction questions and six conditional questions. The day four exercise was made of four inclusive disjunction questions, four exclusive disjunction questions, and four conditional questions. The exercises for each day were interleaved to increase contextual interference (See Literature Review for full explanation of benefits of contextual interference).

4.3.3 *Design and procedure*

This experiment followed a 4 (language item) X 2 (test) X 2 (instruction) full factorial pre-test post-test experimental design. The within-subject factors for this experiment were proficiency in 4 types of language items ('and', 'or', 'xor, and 'if, then')

and scores on the Test of Claim Evaluation (pre- and post-test). The between-subject factor of this experiment was instructional group (implicit or explicit instruction). As described in the Results (p.55) below, a 4 (language item) X 2 (test) X 2 (instructional group) repeated measures analysis of variance was used to analyse the data.

Participant's knowledge of proficiency in truth-functional connectives was evaluated using one form of the Test of Claim Evaluation as a pre-test before the four instructional sessions and a second form as the post-test after the instruction.

Each instructional session was approximately 30-45 minutes in length. In the first day of instruction participants were instructed in the definition of a claim, atomic claim, and a compound claim. On all other days, instruction began with a review of the content taught in the day(s) prior. Following the introduction the type of claim(s) for the day of the lesson were reviewed. In the implicit group this involved using instruction modeled off of the popular ELL grammar book *Grammar Form and Function Level 2* (Milada Broukal, 2008, p.320). This instruction focused on discussing examples of the type of claim and why those claims are used in English. For example, when discussing 'or' the discussion focused on the use of 'or' to provide a choice. When discussing 'if, then' the discussion focused on how the conditional is often used to show a relationship between two claims. In the explicit group, instruction included fewer examples than the implicit instruction, but these examples were complimented by instruction of the claims' truth-function. In both groups, throughout the instructional session questions from participants were answered. However, the content of the answers for the explicit instructional group was always focused on truth-functions, when applicable. The content of the answers for the implicit instructional group was always focused on the general uses of the given claim. After instruction, participants were given a review on how to complete the exercises and were walked through how to interpret the feedback for a sample question

(See Appendix B and C for sample exercise questions and feedback). Participants were told to take their time, ensure they recognized the type of claim, whether they were being asked to make the claim true or false, and to take time to read through all of the feedback. Participants were also encouraged to raise their hands if they had any questions. Upon completion of the quiz, the exercises were reviewed and questions and concerns were discussed as a group.

4.4 Phase 3

This phase of the experiment involved providing explicit instruction to the implicit instructional group from Phase 2. This phase is concerned with hypotheses H5: Is explicit instruction in truth-functions of English connectives a significantly effective method of improving the understanding of truth-functions among ELL students?; and H6: Is implicit instruction in truth-functions of English connectives a significantly effective method of improving the understanding of truth-functions among ELL students?

4.4.1 Participants

Seven ELL's that were in the implicit instructional group in phase 2 took part in this phase of the experiment. One of the seven participants dropped out partway through instruction due to time constraints in coursework.

4.4.2 Materials

Two forms of the Test of Claim Evaluation were used in this experiment. Participant's results from the post-test of phase two were used as the pre-test scores for this experiment. Thus, an additional pre-test was not needed. A third form of the Test of Claim Evaluation was used for the post-test for this phase of the experiment. Exercises in claim evaluation were used to accompany instruction and asides from a change in the

claims used, the exercises used the same design and feedback as those used for the explicit instruction group in the second phase (see Phase 2 Materials, p. 43, for more details).

4.4.3 *Design and procedure*

This experiment employed a 4 (language item) X 2 (test) full factorial pre-test post-test experimental design. The within-subject factors for this phase of the experiment were proficiency in language items ('and', 'or', 'xor, and 'if, then') and scores on the Test of Claim Evaluation (pre- and post-test).

This phase of the experiment followed the same procedure as the explicit group in phase two. This involved a pretest of the understanding of truth-functional connectives (Note: the pretest score used for this intervention was the participants post-test score of phase 2), followed by explicit instruction in truth-functional connectives, which in turn was followed by a post-test on the understanding of truth-functional connectives. No participants were given the same test form twice (For more information on this process see Phase 2 Design and Procedure above, p. 44).

4.5 Phase 4

This phase of the study involved the comparison of the post-test scores for the explicit instructional group in phase two and the post-test scores for the explicit instructional group in phase 3. This phase is concerned with hypotheses H5: Is explicit instruction in truth-functions of English connectives a significantly effective method of improving the understanding of truth-functions among ELL students?; and H6: Is implicit instruction in truth-functions of English connectives a significantly effective method of improving the understanding of truth-functions among ELL students? The collection of

these scores was carried out in Phase 2 and 3. Thus, the methodology of Phase 4 is that of Phase 2 and 3. Phase 4 was included to represent a distinct phase in the analysis of data to investigate whether implicit instruction combined with explicit instruction has a significantly different effect than solely explicit instruction (See Table 3 and 4, p. 34 and 35; Results Phase 4, p. 58-59; and Discussion Phase 4, p. 60-62, for further information on this phase of data analysis).

4.6 Phase 5

This final phase of the experiment was conducted to evaluate whether the instruction provided in phases two and three had an effect on conjunctive bias. That is, these methods were used to evaluate the primary research question (H1): is an increase in the knowledge of truth-functional connectives related to a decrease in conjunctive bias?

4.6.1 Participants

Twenty-five of the participants from Phase 2 began the process to assess the effect that instruction in truth-functional connectives had on conjunctive bias. As noted in Phase 2 and 3 Participants (p.42 and p. 46, respectively), the experiment took place near the end of the term and thus, over the course of the experiment several students dropped out of the study to focus on their course work. Two of the participants who did complete all test forms for this phase of the study were dropped from analysis because of acceptance rates of 40% or higher for the control items (different-noun and different-connective foils). Thus, the final sample included nine participants that ranged between intermediate (n = 1), high-intermediate (n = 1), and advanced (n = 7) English proficiency.

4.6.2 *Materials*

Two forms of the Test of Conjunctive Bias were used in this phase of the experiment (See Phase 1b Materials, p. 38, for the specifications regarding the Test of Conjunctive Bias).

4.6.3 *Design and procedure*

Phase 5 used the Test of Conjunctive bias. The design and procedure was the same as Phase 1B (See Phase 1B Design and Procedure, p. 40-41, for an outline of the design of the Test of Conjunctive Bias used and procedure to collect data using it). The only variation between Phase 1B and Phase 5 is the use of a second form. One form was given to participants as a pre-test before the instruction that took place in Phase 2 and 3. A second post-test form of the Test of Conjunctive Bias was given to participants within one week after receiving all explicit instruction sessions in Phase 2 or 3.

Chapter 5 : Results

5 Results

The following section will provide the results from the the five phases of the experiment.

5.1 Phase 1

Phase 1 is broken into two parts – Phase 1A and Phase 1B. Phase 1A concerned the validation of the Test of Claim Evaluation as well as an assessment of ELL students' understanding of the truth-functional connectives 'and', 'or', 'xor', 'if, then', and 'if and only if'. Phase 1B concerned the validation of the Test of Conjunctive Bias and as well as the assessment of whether conjunctive bias is found among ELL students.

5.1.1 Phase 1A

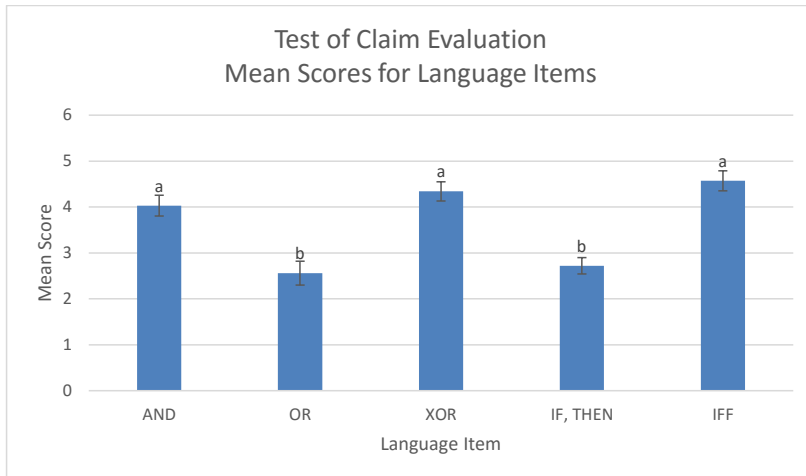
This section will provide results from analyses to assess ELL students understanding of t-f connectives and whether the Test of Claim Evaluation is a valid instrument. Mean (M), standard deviation (SD), and number of participants (n) for scores in the Test of Claim Evaluation are shown in Table 5. Performance across all language items showed a grand mean (M) of 3.54 ($M = 3.54, SE = .13$) (See Materials, p. 35-37, for more information on the Test of Claim Evaluation).

Table 5: Means (*M*), standard deviation (*SD*), and number of participants (*n*) for language items in Phase 1A

English Proficiency	<i>n</i>	AND <i>M</i> (<i>SD</i>)	OR <i>M</i> (<i>SD</i>)	XOR <i>M</i> (<i>SD</i>)	IF, THEN <i>M</i> (<i>SD</i>)	IF AND ONLY IF <i>M</i> (<i>SD</i>)
Intermediate	8	4.06a (1.15)	3.02b (1.47)	4.49a (1.08)	2.48b (.68)	4.27a (1.12)
High-Intermediate	4	4.25a (.65)	.83b (.76)	4.08a (1.62)	2.44b (1.09)	4.49a (1.74)
Advanced	17	3.97a (1.38)	2.75b (1.23)	4.32a (1.09)	2.89b (1.05)	4.73a (1.11)

Note. XOR stands for exclusive ‘or’ claims. Each item score is out of a possible 6. Means across rows that do not share a common subscript differ significantly, $p < .005$

A 5 (language item) X3 (proficiency) ANOVA on scores for truth-functional knowledge of the English language connectives ‘and’, inclusive ‘or’, exclusive ‘or’, ‘if, then’, and ‘if and only if’ as dependent variables and English language proficiency, i.e., intermediate, high intermediate, or advanced, as independent variables only revealed a main effect of language item $F(4, 112) = 19.77, p = .000, \eta_p^2 = .414$. This effect was qualified by results from pairwise comparisons that were conducted for each connective (Note: all pairwise comparisons in this study were conducted with the Bonferroni correction, unless otherwise specified). The results are shown in Figure 2 below. The pairwise comparisons revealed that: scores for ‘and’, the exclusive ‘or’, and ‘if and only if’ were significantly higher than the inclusive ‘or’ ($p < .005$) and ‘if, then’ ($p = .005$) connectives.



Note. Language items that are labelled with different letters differ at $p < .005$

Figure 2: Mean ELL student scores of truth function understanding

5.1.2 Phase 1B

This section will provide results related to whether ELL students exhibited conjunctive bias and whether the Test of Conjunctive Bias is a valid instrument. Results show that most participants took the test seriously, in that acceptance rates for control items (the different-noun and different-connective foils) were low. Mean acceptance rates of different-noun and different-connective foils for conjunctions, disjunctions, and conditionals ranged from 1.67% to 25%. Data from seven participants who accepted these control items in excess of 40% were excluded from further analysis. Due to the fact that these items were intended as controls coupled with the low acceptance of these items among remaining participants, these items were dropped from further analysis.

Mean acceptance rates for the critical test descriptions are presented in Figure 3. A 3(original form) X 3 (test form) ANOVA on the numbers of acceptances, with repeated measures on both factors, found a significant effect of test form $F(2, 24) = 12.27, MS_e = 64.3, p = .000, \eta_p^2 = .51$. The original form X test form interaction was also significant $F(4, 48) = 8.58, MS_e = 20.44, p = .000, \eta_p^2 = .42$. The effect of original form was not significant $F(2, 24) = .026, MS_e = .06, p = .98, \eta_p^2 = .002$. Note that mean squared (MS_e) is reported in the results of the Test of Conjunctive Bias to allow readers to easily compare the results to those of Rader and Sloutsky (2001) whom reported this statistic in their analysis of Conjunctive Bias (Rader & Sloutsky, 2001, p. 844).

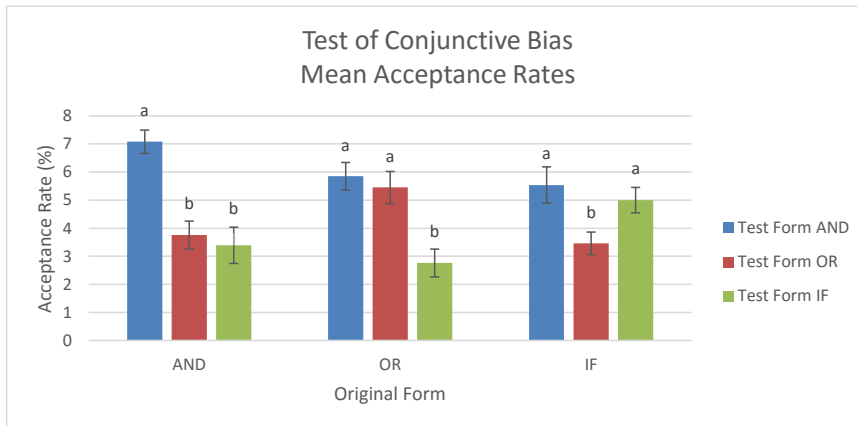
In the analysis of the effect of test form, pairwise comparisons showed that test items that were conjunctions ($M = 61.5\%, SE = 3.7\%$) were significantly more likely to be accepted than disjunction test items ($M = 42.3\%, SE = 3.3\%, p < .005$) and conditional test items ($M = 37.2\%, SE = 3.9\%, p < .005$).

Pairwise comparisons of mean acceptance rates for the test forms within each original form were conducted. All results are shown in Table 6 and Figure 3. Significance was conducted with a 95% confidence interval ($p < .05$). As shown in Table 6 and Figure 3, for original conjunctions, conjunction targets ($M = 70.7\%, SE = 4.2\%$) were accepted significantly more often than disjunction foils ($M = 37.7\%, SE = 4.5\%$) and conditional foils ($M = 33.9\%, SE = 6.5\%$), which did not differ significantly. For original disjunctions, acceptance rates for disjunction targets ($M = 54.6\%, SE = 5.7\%$) and conjunction foils ($M = 58.5\%, SE = 4.9\%$) did not differ significantly, though both were accepted significantly more than conditional foils ($M = 27.6\%, SE = 4.9\%$). For original conditionals, the acceptance rate for conditional targets ($M = 50\%, SE = 4.5\%$) and conjunction foils ($M = 55.4\%, SE = 5.6\%$) were accepted significantly more than disjunction foils ($M = 34.6\%, SE = 4\%$).

Table 6: Means (*M*), standard error (*SE*), and number of participants (*n*) for acceptance rates of targets and different form foils in Phase 1B

Original Form	<i>n</i>	Different Form		
		AND <i>M</i> (<i>SE</i>)	OR <i>M</i> (<i>SE</i>)	IF, THEN <i>M</i> (<i>SE</i>)
AND	8	7.08a (.42)	3.77b (.46)	3.39b (.65)
OR	4	5.85a (.49)	5.46a (.57)	2.77b (.49)
IF, THEN	17	5.54a (.56)	3.46b (.4)	5a (.45)

Note. An item is a target when the original form connective and different form connective match. An item is a foil when the original form connective and the different form connective do not match. Means across rows (within each original form) that do not share a common subscript differ significantly, $p < .005$



Note: Within each original form, means that are labelled with different letters (a or b) differ at $p < .005$ in Bonferonni-adjusted multiple comparisons.

Figure 3: ELL student performance on the Test of Conjunctive Bias

5.2 Phase 2

This section provides results regarding the effects of implicit instruction and explicit instruction of t-f connectives on two groups of ELL students. Mean (M), standard deviation (SD), and number of participants (n) for scores in the Test of Claim Evaluation are shown in Table 7 (See page 37 to 38 for more information on the Test of Claim Evaluation).

A 4 (language item) X 2 (test) X 2 (instructional group) repeated measures ANOVA on scores of truth-functional knowledge (language item) for 'and', 'or', 'xor', and 'if, then' and Test 1 and 2 as within-subject factors and instructional group (implicit or explicit instruction) as between-subjects factors revealed main effects of language item $F(1, 15) = 9.69, p = .000, \eta_p^2 = .558$, test $F(1, 15) = 15.04, p = .001, \eta_p^2 = .501$, and instructional group $F(1, 15) = 1389.09, p = .000, \eta_p^2 = .989$. These effects were qualified by significant interactions between language item and group $F(3, 45) = 2.63, p = .043, \eta_p^2 = .164$, test and instructional group $F(1, 15) = 7.21, p = .017, \eta_p^2 = .325$, language item and test $F(3, 45) = 10.62, p = .000, \eta_p^2 = .415$, and language item, test, and group $F(3, 45) = 3.613, p = .02, \eta_p^2 = .194$ (See Figure 4 for a plot of the mean pre- and post-test score for each instructional group; Figure 5 for a plot of each instructional groups mean score for each language item in test 1 and test 2; Discussion below for a detailed description of the significant within- and between-subjects differences).

Table 7: Means (M), standard deviation (SD), and participants (n) for pre- and post-test language items in Phase 2

Instructional Group		AND		OR		XOR		IF, THEN	
		<i>M</i>		<i>M</i>		<i>M</i>		<i>M</i>	
		(SD)	(SD)	(SD)	(SD)	(SD)	(SD)	(SD)	(SD)
		Pre	Post	Pre	Post	Pre	Post	Pre	Post
Implicit	7	4.64a (.85)	4.57a (.88)	2.74a (1.25)	3.42a (.91)	4.74a (.48)	4.85a (.56)	3.28a (.61)	3.36a (.51)
Explicit	10	4.65a (1)	4.9a (.78)	3.08a (1.52)	5.87b (.22)	4.98a (.87)	5.32a (.83)	3.05a (1.19)	4.2b (.94)

Note. XOR stands for exclusive ‘or’ claims. Each item score is out of a possible 6. Pre- and post-test scores under each connective and within each instructional group that do not share a common subscript differ significantly, $p < .001$.

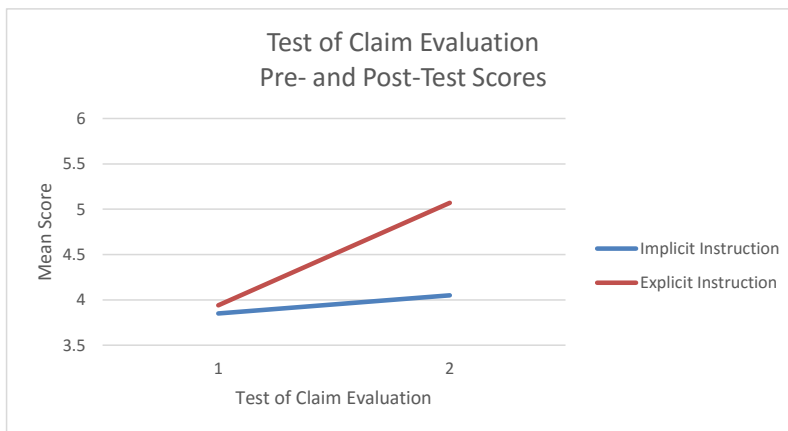
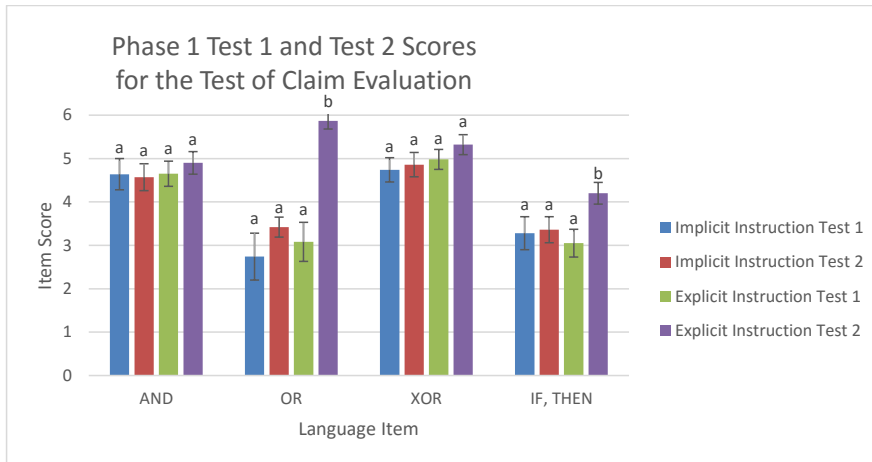


Figure 4: Test of Claim Evaluation pre- and post-instruction scores



Note. XOR stands for exclusive ‘or’ claims. Each item score is out of a possible 6. Pre- and post-test scores under each connective and within each instructional group that do not share a common subscript differ significantly, $p < .001$.

Figure 5: Comparison of pre- and post-test scores of each language item between instructional groups.

5.3 Phase 3

This section reports the results of the effects that explicit instruction in t-f connectives had on the understanding of t-f connectives for participants who received implicit instruction in Phase 2. Mean (M), standard deviation (SD), and number of participants (n) for scores in the Test of Claim Evaluation are shown in Table 8. (See page 37 to 38 for more information on the Test of Claim Evaluation).

A 4 (language item) X 2 (test) within-subjects repeated measures ANOVA on scores of truth-functional knowledge (language item) for ‘and’, ‘or’, ‘xor’, and ‘if, then’ and Test 1 and 2 as within-subject factors revealed a main effect of test $F(1, 5) = 111.85$,

$p = .000$, $\eta_p^2 = .957$. Although there was not a main effect of language item $F(3, 15) = 3.104$, $p = .058$, $\eta_p^2 = .383$ it should be noted that language item approached significance ($p < .05$). These effects were qualified by a significant interaction between language item and test $F(3, 15) = 3.67$, $p = .037$, $\eta_p^2 = .423$. Pairwise comparisons showed a significant difference in 'or', 'xor, and 'if,then' pre- and post-test scores (See Figure 6 for a plot of mean pre- and post-test scores for the implicit-explicit instructional group; See Figure 7 for a plot of the implicit-explicit instructional group mean score for each language item in test 1 and test 2; See Discussion below for a detailed description of the significant within- and between-subjects differences).

Table 8: Means (M), standard deviation (SD), and number of participants (n) for language items in Phase 3

Language Item	<i>n</i>	Test 1 <i>M (SD)</i>	Test 2 <i>M (SD)</i>
AND	6	4.42a (0.86)	4.92a (0.74)
OR	6	3.38a (0.99)	5.42b (0.67)
XOR	6	4.75a (0.52)	5.56b (0.55)
IF, THEN	6	3.43a (0.53)	5.31b (0.82)

Note. XOR stands for exclusive 'or' claims. Each item score is out of a possible 6. Pre and post scores within each connective (each row) that do not share a common subscript differ significantly, $p < .05$

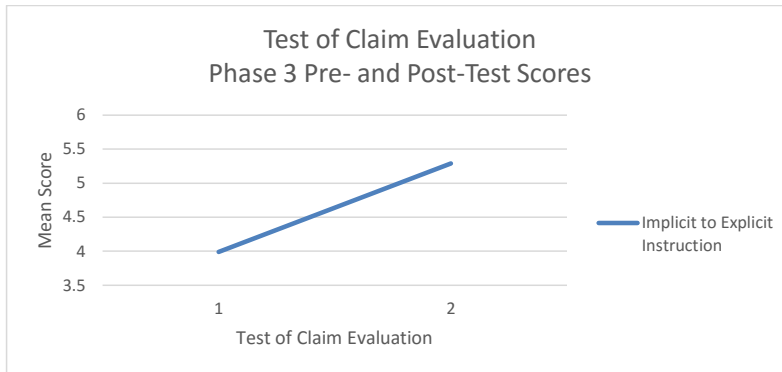
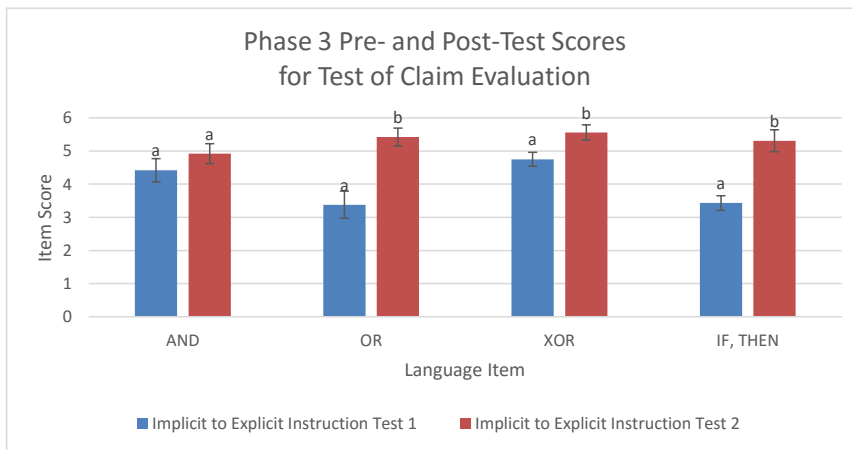


Figure 6: Effect of explicit instruction on mean truth-functional connective understanding



Note. XOR stands for exclusive ‘or’ claims. Each item score is out of a possible 6. Pre and post scores within each connective (each row) that do not share a common subscript differ significantly, $p < .05$

Commented [e1]: Each column

Figure 7: Effect of explicit instruction on truth-functional connective understanding

5.4 Phase 4

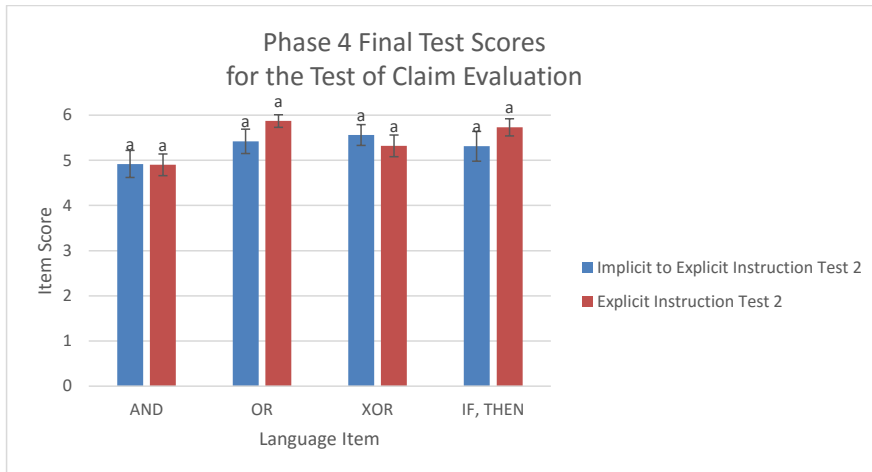
This section report on the t-f understanding of the participants who received both implicit and explicit instruction as well as the participants who only received explicit t-f instruction. Mean (*M*), standard deviation (*SD*), and number of participants (*n*) for scores in the Test of Claim Evaluation are shown in Table 9 (See page 37 to 38 above for more information on the Test of Claim Evaluation).

A 4 (language item) X 2 (instructional group) between-subjects ANOVA on post-explicit-instruction (Test 2) scores of truth-functional knowledge (language item) for ‘and’, ‘or’, ‘xor’, and ‘if, then’ and instructional group (implicit-explicit or explicit instruction) revealed no main effects. Though between-groups effects for total inclusive ‘or’ score did approach significance $F(1, 14) = 4.027, p = .064, \eta_p^2 = .223$ (See Figure 8 for a plot of each instructional groups mean score for each language item in Test 2; See Discussion below for a detailed description of the non-significant between-subjects effects).

Table 9: Means (M), standard deviation (SD), and number of participants (n) for language items in Phase 4

Instructional Group	<i>n</i>	AND <i>M</i> (<i>SD</i>)	OR <i>M</i> (<i>SD</i>)	XOR <i>M</i> (<i>SD</i>)	IF, THEN <i>M</i> (<i>SD</i>)
Implicit-Explicit Instruction	6	4.92a (.74)	5.42a (.67)	5.56a (.55)	5.31a (.82)
Explicit Instruction	10	4.9a (.73)	5.87a (.22)	5.32a (.83)	5.73a (.49)

Note. XOR stands for exclusive ‘or’ claims. Each item score is out of a possible 6. Scores between instructional groups (within each column) that do not share a common subscript differ significantly, $p < .05$



Note. XOR stands for exclusive ‘or’ claims. Each item score is out of a possible 6. Pre and post scores within each connective (each row) that do not share a common subscript differ significantly, $p < .05$

Figure 8: Implicit-explicit instruction and explicit-only instruction groups understanding of truth-functional connectives

5.5 Phase 5

The results of this section will allow us to answer the primary research question (H1): is an increase in knowledge of truth-functional connectives related to a decrease in conjunctive bias? Results show that most participants took the test seriously, in that acceptance rates for control items (the different-noun and different-connective foils) were low. Mean acceptance rates of different-noun and different-connective foils for conjunctions, disjunctions, and conditionals ranged from 5% to 36.67%. Due to the fact that these items were intended as controls coupled with the low acceptance of these items among remaining participants, these items were eliminated from further analysis.

Mean acceptance rates for the critical test descriptions are presented in Table 10 and Figure 9. As noted in the results of Phase 1A, mean squares (MS_e) were included in the results of the Test of Conjunctive Bias to facilitate comparison with Rader and Sloutsky (2001) who included mean squares in their results. A 3(original form) X 3 (test form) X 2 (test) repeated measures ANOVA found a significant main effect of test form $F(1.19, 9.52) = 14.73$, $MS_e = 97.24$, $p = .003$, $\eta_p^2 = .65$. Note: Mauchly's Test of Sphericity was significant for test form ($p = .018$) and the Greenhouse-Geisser correction has been applied to effects of test form. There was also significant main effect of test $F(1, 8) = 5.68$, $MS_e = 16.691$, $p = .04$, $\eta_p^2 = .42$. These results were qualified by significant interaction effects of original form X test form $F(4, 32) = 11.61$, $MS_e = 45.11$, $p = .000$, $\eta_p^2 = .59$, different form X test $F(2, 16) = 4.4$, $MS_e = 7.12$, $p = .03$, $\eta_p^2 = .36$, and original form X test form X test $F(4, 32) = 10.06$, $MS_e = 15.12$, $p = .000$, $\eta_p^2 = .56$. No other significant effects were found.

Table 10: Means (M), standard error (SE), and number of participants (n) for acceptance rates of targets and different form foils in Phase 5

Original Form	n	Different Form					
		AND		OR		IF, THEN	
		M (SE)		M (SE)		M (SE)	
		Pretest	Post-test	Pretest	Post-test	Pretest	Post-test
AND	9	6.89a (.46)z	7.22a (.64)z	4.89a (.65)z	3.56b (.5)z	3.44a (.77)z	2.44a (.65)z
OR	9	5.56a (.41)x	3.33b (.73)x	5.56a (.67)z	7a (.58)x	2.67a (.69)x	2.33a (.55)z
IF, THEN	9	6.44a (.58)zx	4.11b (.74)x	5.33a (.82)z	3.56b (.5)z	4.56a (.8)z	6b (.58)x

Note. An item is a target when the original form connective and different form connective match. An item is a foil when the original form connective and the different form connective do not match. Pre- and post-test mean pairs for each connective that do not share a common subscript (a or b) differ significantly, $p < .05$. In each column means that do not share a common subscript (z or x) differ significantly, $p < .05$

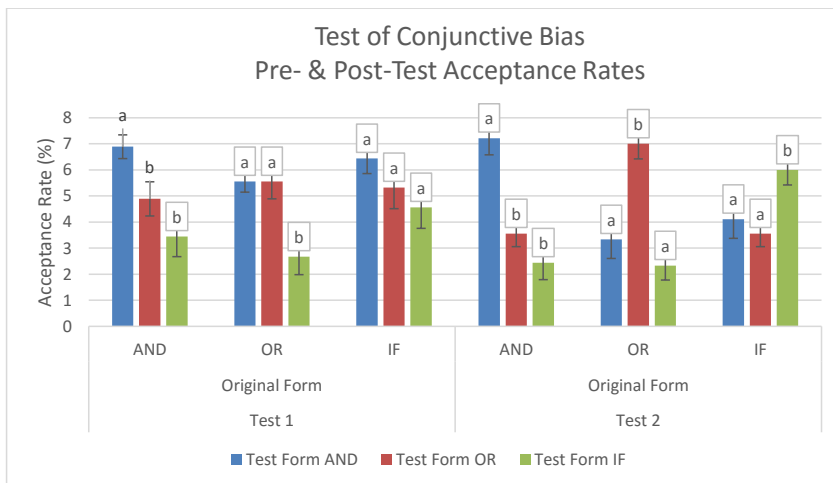
Pairwise comparisons of test form were conducted within each test. Comparisons within test 1 showed acceptance rates of conjunction test forms ($M = 62.9\%$, $SE = 3.9\%$) were accepted significantly more than disjunction test forms ($M = 52.6\%$, $SE = 5.1\%$), which in turn were accepted significantly more than conditional test forms ($M = 35.6\%$, $SE = 6.5\%$).

Pairwise comparisons of test form within test 2 showed that acceptance rates of conjunction test forms ($M = 48.9\%$, $SE = 4.6\%$) and disjunction test forms ($M = 47\%$, $SE = 2.9\%$) did not differ significantly. Though both had acceptance rates significantly greater than conditional test forms ($M = 35.9\%$, $SE = 4.2\%$).

Pairwise comparisons of mean acceptance rates for the test forms within each original form within each test were conducted. The results are noted in Figure 9. In Test 1, as indicated in the figure, for original conjunctions, conjunction targets ($M = 68.9\%$, $SE = 4.6\%$) were accepted significantly more than disjunction foils ($M = 48.9\%$, $SE = 6.6\%$) and conditional foils ($M = 34.4\%$, $SE = 7.7\%$). For original disjunctions, acceptance rates for disjunction targets ($M = 55.6\%$, $SE = 6.7\%$) and conjunction foils ($M = 55.6\%$, $SE = 4\%$) did not differ significantly, although both were accepted more often than conditional foils ($M = 26.7\%$, $SE = 6.9\%$). For original conditionals, the acceptance rate for conditional targets ($M = 45.6\%$, $SE = 8\%$) did not differ significantly from conjunction foils ($M = 64.4\%$, $SE = 5.8\%$) or disjunction foils ($M = 53\%$, $SE = 8\%$). These results match those presented in Phase 1B (See Results, p. 52-54, and Figure 3, p.69, for comparison) and were very similar to those found in Rader and Sloutsky (2001) (See Figure 1, p.38, for comparison).

Pairwise comparisons of mean acceptance rates for the test forms within each original form for Test 2 were conducted. As indicated in Figure 9, for original conjunctions, conjunction targets ($M = 72\%$, $SE = 6.4\%$) were accepted significantly more than disjunction foils ($M = 35.6\%$, $SE = 5\%$) and conditional foils ($M = 24.4\%$, $SE = 6.5\%$). For original disjunctions, acceptance rates for disjunction targets ($M = 70\%$, $SE = 5.8\%$) were accepted significantly more than conjunction foils ($M = 33.3\%$, $SE = 7.3\%$) and conditional foils ($M = 23\%$, $SE = 5.5\%$). For original conditionals, acceptance rates for conditional targets ($M = 60\%$, $SE = 5.8\%$) were significantly higher than conjunction foils ($M = 41\%$, $SE = .74$) and disjunction foils ($M = 35.6\%$, $SE = 5\%$). These results do not match those of Test 2, Phase 1b, or Rader and Sloutsky (2001). To assess the significant differences between Test 1 and 2 pairwise comparisons were conducted for the interaction of original form X test form X test interaction.

In pairwise comparisons between test 1 and 2 for the original form X test form X test interaction many significant effects (p 's < .05) were found that are indicative of an elimination of conjunctive bias in ELL students (See Discussion for more detail). For original conjunctions, acceptance rates for disjunction foils decreased by 13%. For original disjunctions, acceptance rates of conjunctive foils dropped by 22% and although not significant ($p = .08$) acceptance rates of disjunction targets increased by 14%. For original conditionals, acceptance rates of target conditionals increased by 14% and acceptance rates of conjunction foils and disjunction foils dropped 23% and 18%, respectively. These results indicate significant improvements in accurate recall of disjunctions and conditionals as well as a reduction in the tendency to recall disjunctions and conditionals and conjunctions (See Figure 9 for a graphical representation of these differences). More details analysis of these results will occur in the Discussion.



Note: Within each original form, means that are labelled with different letters (a or b) differ at $p < .05$ in Bonferonni-adjusted multiple comparisons.

Figure 9: Conjunctive bias pre- and post- explicit instruction in truth functions

Chapter 6 : Discussion

6 Discussion

This discussion is divided into six different sections – one for each phase of data analysis and a concluding section which will summarize the results from each phase and draw from those the general conclusions that the sum of the analyses show. To accompany the discussion, Table 1 has been presented again (see below). This table includes a list of the hypotheses tested in this study. For further clarification refer to Table 3 and 4 (p. 34 & 35) for a summary of the purpose of each phase, the hypotheses addressed in each phase, and the completed tests and instruction in each phase.

Hypothesis Name	Hypothesis
Hypothesis 1 (H1)	An increase in the knowledge of truth-functional connectives is related to a decrease in conjunctive bias.
Hypothesis 2 (H2)	Untrained ELL students will perform on the Test of Claim Evaluation as predicted by mental model theory.
Hypothesis 3 (H3)	Untrained ELL students will exhibit conjunctive bias - as predicted by performance on the Test of Claim Evaluation by Rader and Sloutsky (2001).
Hypothesis 4 (H4)	Untrained ELL students will show a poor understanding of truth-functional connectives.
Hypothesis 5 (H5)	Explicit instruction in truth-functions of English connectives is a significantly effective method of improving the understanding of truth-functions among ELL students.
Hypothesis 6 (H6)	Implicit instruction in truth-functions of English connectives is not a significantly effective method of improving the understanding of truth-functions among ELL students.
Hypothesis 7 (H7)	Explicit instruction in truth-functions of English connectives is significantly more effective than implicit instruction in English connectives.

6.1 Phase 1

The aim of Phase 1 was the validation of the measures used for assessment and an evaluation of ELL students' conjunctive bias and knowledge of truth-functions of English language connectives. Phase 1A discusses the results of the Phase 1 analysis of truth-functional knowledge (H4) as well as the validity of the Test of Claim Evaluation (H3) by comparing results with the predictions of model theory. Phase 2B of this section discusses conjunctive bias in ELL students (H3) and the validity of the Test of Conjunctive Bias by comparing the results with those of Rader and Sloutsky (2001) (H3).

6.1.1 Phase 1A

The aim of Phase 1A was to assess ELL students' knowledge of truth-functions through their performance on the Test of Claim Evaluation (H4) and to assess the validity of the Test of Claim Evaluation by comparing the performance of ELL students with the predictions of model theory (H2). Twenty-nine ELL's ranging in English proficiency from intermediate, high-intermediate, to the advanced level - completed the Test of Claim Evaluation.

No significant effects were found for level of English proficiency. This may be due to the limited range in proficiency level among these participants – or the general lack of knowledge in- and instruction of- truth-functional connectives in the current ELL curriculum. Currently, ELL students are not explicitly taught truth-functions in their language program and thus, the latter is a strong possibility.

Model theory predicts that the difficulty individuals untrained in logic will have with each connective is predicted by the number of models needed to make that claim true (See section Literature Review, p. 24; Goodwin & Johnson-Laird, 2011, p.50).

Results showed participants scored between a 68% and 75% proficiency level when evaluating connectives that required one or two models ('and', 'xor', and 'if and only if') and between a 37% and 43% proficiency level when evaluating connectives that required three mental models ('or' and 'if, then'). The difference between these groups of language items was significant ($p < .05$) and showed a very strong effect size. The significant differences in these scores align with the prediction of performance by model theory – providing construct validity to the Test of Claim Evaluation. It should be noted, that a possible explanation for the poor proficiency of 'or' may be due in part to the conventional interpretation of disjunctions as exclusive disjunctions (See Literature Review, p. 17-23, for more information).

Results from the Test of Claim Evaluation show a grand mean (M) performance across all language items of 3.54 ($M = 3.54, SE = .13$) – or 59% proficiency. This mean performance of ELL students on the Test of Claim Evaluation indicates that they have a poor understanding of truth-functional connectives – providing reason to conduct an instructional intervention.

6.1.2 Phase 1B

The aim of Phase 1B was to assess whether ELL students suffered from conjunctive bias (H3) and to assess the validity of the Test of Conjunctive Bias by comparing the results to those of Rader and Sloutsky (2001) (H3).

Rader and Sloutsky (2001) discovered the phenomenon of conjunctive bias through the assessment of “twenty-nine undergraduates from a large Mid-western [American] university” (p. 842). It would be unreasonable to assume that a significant group of these undergraduates were ELL's. So, before continuing with the current thesis

13 ELL students ranging in English proficiency from intermediate, high-intermediate, to an advanced level – completed the Test of Conjunctive Bias.

There are two conditions that must be met to recognize conjunctive bias. Firstly, the acceptance level of target conjunctions must be significantly greater than that of target disjunctions and target conditionals. Secondly, the acceptance level of conjunction foils across original forms must be the same as- or greater than- the acceptance levels of disjunction and conditional targets. These two conditions form the requirements of the conjunctive bias hypothesis – and thus, must be met for a positive evaluation of the presence of conjunctive bias.

A 3 (original form) X 3 (test form) ANOVA returned very large and significant effects ($p < .001$) for test form and the original X test form interaction. In the effect of test form, results almost perfectly mirrored those of Rader and Sloutsky (2001) (See Figure 1 on p. 38) and those from Phase 1 (See Figure 3 on p. 69) for a visual comparison. Just as in Rader and Sloutsky (2001), conjunctions were significantly more likely to be accepted than disjunctions and conditionals (p. 843). Unlike Rader and Sloutsky (2001), disjunctions were not significantly more likely than conditionals to be accepted (p. 843). This may be due to the higher acceptance rate of conditionals in the group of ELL students in the present study than in the participants in Rader and Sloutsky's (2001) study. However, this small difference does not significantly impact the evaluation of the conjunctive bias hypothesis. As stated above, this hypothesis is concerned with the relation of acceptance rates of conjunction targets to disjunction and conditional foils as well as the relation of acceptance rates of conjunction foils to disjunction and conditional targets – not the relation of acceptance rates for disjunction and conditional foils. These results from the main effect of test form show that ELL students have more accurate recall of 'and' claims, than 'or' claims and 'if, then' claims.

Thus, the results of the main effect of test are consistent with the first condition of the conjunctive bias hypothesis.

The results from the original X test form interaction had a very large and significant ($p < .05$) effect size and mirrored the results of Rader and Sloutsky (2001) perfectly. As said by Rader and Sloutsky (2001):

The participants readily discriminated original conjunctions from disjunctive and conditional foils (the participants were much more likely to accept as *old* those exact descriptions [conjunction original form] than they were to accept disjunction and conditional foils). At the same time, the participants poorly discriminated original disjunctions and conditionals from conjunctive foils (they were equally likely to accept the originals and their conjunction foils) (p. 844).

These results from the original X test form interaction satisfy the second condition of the conjunctive bias hypothesis.

The results from both the main effect of test and of the original X test form interaction are consistent with the conjunctive bias hypothesis and mirror the results of Rader and Sloutsky (2001). Thus, we find that the results from phase 1b provide content validity to the Test of Conjunctive Bias and we can conclude that ELL students have conjunctive bias.

6.2 Phase 2

Phase 2 concerns the first instructional intervention in truth-functional connectives in this thesis. This phase of the experiment contributes to answering: H5: Is explicit instruction in truth-functions of English connectives a significantly effective method of improving the understanding of truth-functions among ELL students?; H6: Is

implicit instruction in truth-functions of English connectives a significantly effective method of improving the understanding of truth-functions among ELL students?; and H7: Is explicit instruction in truth-functions of English connectives significantly more effective than implicit instruction in English connectives? As noted in the Design and Procedure subsection of Phase 2 (p.44), instruction in phase 2 was split into two groups, implicit and explicit instruction of t-f connectives. Both groups received the same practice exercises, but the explicit instruction group received instruction and feedback focusing on truth-functional rules – whereas the second group received general instruction regarding the common uses of a given claim. As noted in Materials (p.43), the Test of Claim Evaluation assesses the same problems that are used as exercises during instruction. Each group spent the same amount of time discussing claims and worked through the same number of problems - evaluating the circumstances leading to the truth or falsity in the same number of claims. The matching of each instructional group's time-on-task controlled for practice effects that may increase performance in the exercises evaluated in the Test of Claim Evaluation. This matching of time on task, coupled with the differentiation in instruction and feedback in this phase allowed for the controlled measure of between-group differences of explicit vs. implicit instruction on pre-and post-test scores on the Test of Claim Evaluation.

The 4 (language item) X 2 (instructional group) X 2 (pre-/post-test) repeated measures ANOVA showed significant ($p < .05$) and very large effects. There was a main effect of language item that showed significant differences in scores between language items. There was a main effect of test, such that Test 2 scores were significantly higher than Test 1 scores. The main effect of instructional group showed that the explicit instruction group performed significantly higher than the implicit instructional group. All of these main effects were qualified by significant interactions ($p < .05$) with large to very large effect sizes. The interaction effect of language item and group showed a large

difference in language item scores between the groups. This difference showed that the explicit group was improving significantly more than the implicit group's knowledge of truth-functional connectives. The interaction effect of language item and test showed a significant increase in proficiency in truth-functional connectives between the pre- and post- test. These differences are discussed in more detail in the following paragraph regarding the three way interaction of language item, test, and instructional group. The interaction effect of test and instructional group showed a significantly larger increase between pre- and post-test scores for proficiency of truth-functional connectives in the explicit instruction group than in the implicit instruction group. As shown in figure 4, the explicit instructional group had a mean improvement of 19% bringing the mean post-test score to 85%. This contrasted strongly with the implicit instruction group that had a mean improvement of 3% bringing the mean post-test score to 68%. These results show the need for explicit instruction if significant increases in knowledge of truth-functional connectives are to occur.

Of most interest, there was a large interaction effect of language item, test, and instructional group. This interaction effect showed a large difference between groups in their pre- and post- instruction proficiency in truth-functional connectives. That is, the explicit group's proficiency in truth-functional connectives increased significantly more than the implicit instructional group over the course of the instruction. In particular the significant increase in performance of the explicit instructional group occurred in their proficiency of the inclusive 'or' and conditional 'if, then'. Regarding proficiency of 'or' the explicit group had a mean improvement of 47% bringing their post-test proficiency of 'or' to 98%. This is contrasted with the implicit instructional groups' mean improvement of 11%, which brought their post-test proficiency of 'or' to 57%. Regarding proficiency of 'if, then' the explicit group had a mean improvement of 19%, which brought their post-test proficiency of 'if, then' to 70%. This is strongly contrasted with the implicit

instruction groups' mean improvement of 1% bringing their post-test proficiency of 'if, then' to 56%. Based on these quantitative results, we can see that explicit instruction in the truth-functions of connectives that require three mental models (in a statement with two variables) significantly increases proficiency in those connectives. From mental model theory we can predict that this is due to ELL students forming fully explicit models (Literature Review, p. 24; Johnson-Laird, 2001, p. 435), the principle of simplifying models (Literature Review p. 25; Goodwin & Johnston-Laird, p. 44), and/or the change in representation of models that represent the true instances of a claim to models that represent the false instances of a claim (Literature Review p. 25, Goodwin & Johnston-Laird, p.44). In the two latter reasons provided by model theory this would lead to a reduction in the number of mental models, which lessens cognitive load allowing more accurate assessment of claims (See Literature Review, p. 25). However, further assessment, such as qualitative interviews of participants may be required to assess whether the improvement in proficiency is from holding fully explicit models, simplifying models, or due to a switch in model representation from true to false models. Informal conversations with participants during instruction showed that many students were unaware that 'or' had an inclusive function. Thus, the significant improvement in proficiency of 'or' is likely due less to changes in cognitive load than due to ELL students newfound ability to form fully explicit mental models.

6.3 Phase 3

Phase 3 of the experiment involved providing explicit instruction to the implicit instructional group in Phase 2. This group will be referred to as the implicit-explicit group, reflecting both types of the instruction they received. This phase was concerned with evaluating the effect that explicit instruction would have on a group that had

previously received implicit instruction by assessing whether the explicit instruction would be accompanied by a significant increase in t-f understanding. These results have implications for H5, H6, and H7, which are listed in Table 1 (p. 4) and in the discussion of Phase 2 above (p.70-73). As noted in Materials (p. 46) the pre-test score used for this phase of the experiment was the Phase 2 score of the implicit instructional group *after* they received the implicit instruction. A large main effect of test showed that the implicit-explicit instructional groups' proficiency in truth-functional connectives significantly improved following explicit instruction. This group's mean proficiency in truth-functional connectives improved by 22% bringing them to a post-explicit-instruction score of 89% (See Figure 6, p.75, for a graphical representation of this change. This improvement is very similar to the 19% mean improvement in proficiency of truth-functional connectives that was seen by the explicit instruction group in Phase 2.

The results showed the interaction effect of language item and test was significant ($p < .05$) and very large. Regarding truth-functional proficiency of the inclusive disjunction 'or', participants had a mean increase of 34% - raising their final proficiency level to 90%. The proficiency of the exclusive disjunction 'xor' increased by 14% to a final proficiency level of 93%. The proficiency of the conditional 'if, then' increased by 31% to a final proficiency level of 89%. These differences between post-implicit instruction scores and post-explicit instruction scores further affirm the effect of explicit truth-functional instruction on proficiency in truth-functional connectives. This supports the hypothesis that explicit instruction in truth-functions of English connectives is a significantly effective method of improving the understanding of truth-functions among ELL students (H5). These results, showing a dramatic increase in t-f understanding from post-implicit instruction to post-explicit instruction, also support the hypothesis that explicit instruction in truth functions of English connectives is significantly more effective than implicit instruction in English connectives (H7).

6.4 Phase 4

Phase 4 of the study involves the comparison of the explicit instructional group and the implicit-explicit instructional group in their proficiency of truth-functional connectives. In Phase 2 and 3 we showed that explicit instruction in truth functions of English connectives was significantly effective in improving understanding of truth functions of English connectives among ELL students (H5) and that it was significantly more effective than implicit instruction (H7). Through comparisons of t-f understanding of the group that received implicit and explicit instruction to the group that only received explicit instruction we assessed whether there is a significant difference in scores between groups. This analyses showed whether the implicit instruction has a positive effect, negative effect, or no effect on t-f understanding when used in conjunction with explicit instruction. Simply put, this comparison was made to assess whether the extra instructional time received by the implicit-explicit group led to a significant difference in post-explicit-instruction scores on the Test of Conjunctive Bias (H6 & H7). In addition, differences could be caused by multiple exposures to the treatment condition - referred to as carry over effects. Results from this analysis that show significant differences between the groups will indicate the possibility of carry over effects and the possibility that implicit instruction has an effect on t-f understanding.

A 4 (language item) X 1 (test) X 2 (instructional group) multivariate ANOVA was conducted. The multivariate ANOVA did not reveal any significant main effects. However, there was a very large between-group effect for the inclusive disjunction 'or' that approached significance ($p = .06$). This difference can be seen in Figure 8. As shown in the figure, the explicit instruction only group showed a greater truth-functional proficiency for 'or' – although this only approached significance. It is not clear what

caused this difference, but it does not indicate that the extra implicit instruction received by the implicit-explicit instructional group of Phase 3 caused significant improvements in performance. From the results of this phase we can conclude that the implicit instruction did not have a significant effect on proficiency in assessing truth-functional connectives – nullifying H6. Furthermore, these insignificant differences between groups show that carry over effects were unlikely. These results support the hypothesis that explicit instruction in t-f connectives is significantly more effective than implicit instruction in these same connectives.

It should be noted that the lower proficiency of ‘or’, which approached significance, suggests the possibility of a negative effect of implicit instruction on truth function understanding. Further assessment using a larger sample and increased time spent in each instructional form may in fact lead to the result that implicit instruction has a detrimental effect on knowledge gains. Although this is speculation, the increased time on task in implicit instruction that allows learners to form their own rules may lead them to reinforce incorrect or incomplete rules that impede future progress (See Recommendations of Further Research, p. 90-91, for further discussion).

6.5 Phase 5

Phase 5 of the study involves the evaluation of whether an increase in knowledge of truth-functional connectives has an effect on conjunctive bias (H1). As noted in Phase 5 Methodology (p. 48), 25 of the participants who took part in Phase 2 began the process to assess whether knowledge of truth-functional connectives has an effect on conjunctive bias. However, due to attrition throughout the experiment and unreasonably high acceptance rates from two participants, the final sample for this phase of the experiment included nine participants. Participants were assessed for conjunctive bias before

receiving any truth-functional instruction and after receiving explicit truth-functional instruction.

As stated in the conjunctive bias hypothesis there are two conditions that must be met to recognize conjunctive bias. Firstly, the acceptance level of target conjunctions must be significantly greater than that of target disjunctions and target conditionals. Secondly, the acceptance level of conjunction foils across original forms must be the same as or greater than the acceptance levels of disjunction and conditional targets.

The results from Test 1 – the pre-instruction Test of Conjunctive Bias (See Figure 9, p. 83), align with those of Phase 1B (For a visual comparison see Figure 3, p.59) and Rader & Sloutsky (2001) (For a visual comparison see Figure 1, p. 38) – exemplifying conjunctive bias. Pairwise comparisons of test form within test 1 showed that conjunction test forms were accepted significantly more than disjunction test forms, which were accepted significantly more than conditional test forms. These results satisfy the first requirement of the conjunctive bias hypothesis noted above.

Pairwise comparisons of mean acceptance rates for the test forms within each original form for Test 1 found that for original conjunctions, conjunction targets were accepted significantly more than disjunction foils and conditional foils. For original disjunctions, acceptance rates for disjunctions and conjunction foils did not differ significantly and both were accepted significantly more than conditional foils. Finally, for original conditionals there was no difference in acceptance rate between the conditional target, conjunction foils, and disjunction foils. As these results show acceptance rates of targets and conjunction foils did not show a significant difference. Thus, from both the pairwise comparisons of test form within test 1 and pairwise comparisons of test forms within each original form we see that ELL students “readily discriminated conjunctive targets from disjunctive and conditional foils, although failing reliably to discriminate

conditional targets” (Rader & Sloutsky, 2001, p.846) and disjunction targets from conjunction foils. Furthermore, similar to Rader and Sloutsky (2001) the high acceptance of conjunctive foils when tasked with identifying target conditionals suggests that conditionals are frequently represented as conjunctions in memory (p.844). Unlike Rader and Sloutsky (2001), the insignificant difference in acceptance rate between target disjunction and conjunctions suggests that among ELL students disjunctions may frequently be represented as conjunctions.

The primary goal of this thesis is to address whether instruction in truth-functional connectives reduces conjunctive bias. Thus, we will now discuss the results of the Test 2 scores of the Test of Conjunctive Bias. Test 2 was conducted after each individual had received the explicit instruction in truth-functional connectives. Results of this analysis can be seen in Figure 8. The same analyses that were conducted for test one in Phase 5, above, were also carried out for the scores of Test 2 – the post-instruction Test of Conjunctive Bias. The results shown in Figure 9 depict a very different set of results than those presented for Test 1b in Phase 1, Test 1 in Phase 5, and Rader and Sloutsky (2001).

Pairwise comparisons of test form within Test 2 showed that acceptance rates of conjunction test forms did not differ significantly from acceptance rates of disjunction test forms. Both conjunction test forms and disjunction test forms did have higher acceptance rates than conditional test forms. These results show that following instruction in truth-functional connectives, target conjunctions do not have a significantly higher acceptance rate than both target disjunctions and conditionals. Thus, the first condition of the conjunctive bias hypothesis has not been met. Indicating that instruction in truth-functional connectives has reduced conjunctive bias.

Pairwise comparisons of mean acceptance rates for the test forms within each original form for Test 2 found that for original conjunctions, conjunction targets were

accepted significantly more than disjunction foils and conditional foils. For original disjunctions, acceptance rates for disjunction targets were accepted significantly more than conjunction foils and conditional foils. Note that in Test 1 original disjunctions and conjunction foils did *not* show significant differences in acceptance rates. For original conditionals, acceptance rates for conditional targets were significantly higher than conjunction foils. Again, this contrasts strongly with Test 1 where conditional targets did not differ significantly from conjunction foils *or* disjunction foils. These results show that after truth-functional instruction ELL students show significantly higher acceptance rates of disjunction and conditional test forms, than acceptance rates of conjunction foils. Thus, the second condition of the conjunctive bias hypothesis has not been met in the group of ELL students after receiving instruction in truth-functional connectives. These results show that after truth-functional instruction ELL students successfully discriminated between conjunction foils and disjunction and conditional targets.

The significance of these results is reinforced by the fact that among tests for conjunctive bias by Rader and Sloutsky (2001), in Phase 1B, and in the pre-instruction test (Test 1) of this phase, the post-truth-functional instruction test (Test 2) of Phase 5 was the only assessment of conjunctive bias that: 1) did not find significant results indicating conjunctive bias and, more importantly, 2) found significant results that were the opposite of both conditions necessary to confirm the conjunctive bias hypothesis.

In order to assess the statistically different differences between conjunctive bias pre- and post- explicit truth-functional instruction, a final analysis of pairwise comparisons between Test 1 and 2 for the original form X test form X test interaction were conducted. These results showed significant differences in target and foil acceptance rates from the pre-truth-functional instruction (Test 1) Test of Conjunctive Bias to the post-truth-functional instruction (Test 2) Test of Conjunctive Bias. For

original conjunctions, acceptance rates for disjunction foils decreased by 13%. This indicates an improvement in the recognition and memory of conjunctions. For original disjunctions, acceptance rates of conjunctive foils dropped by 22% and acceptance rates of disjunction targets increased by 14% - though this latter increase only approached significance ($p = .08$). The former improvement indicates that after explicit instruction in truth-functions of English connectives, disjunctions were significantly less likely to be represented in memory as conjunctions. Although statistical significance ($p < .05$) was not reached for the improvement in the acceptance rate of disjunction targets, this change which approached significance suggests that with more time in instruction, completing exercises, and perhaps a larger group of participants, a significant increase in acceptance rate of disjunction targets might be found. This would indicate that explicit instruction in truth-functional connectives improves memory of disjunctions. Lastly, pairwise comparisons for original conditionals showed that acceptance rates of target conditionals significantly increased by 14% and was accompanied by a drop in acceptance rates of conjunction and disjunction foils of 23% and 18%, respectively. This result indicates that explicit instruction in truth-functional connectives significantly improves memory of conditionals. These results are shown in Figure 9. The two graphs provide a depiction of the stark contrast in conjunctive bias pre- and post- explicit instruction in truth-functional connectives.

6.6 General discussion

The quantitative analysis from the various phases that occurred over the course of this study revealed several important findings. Firstly, the untrained ELL students' performance on the Test of Claim Evaluation aligned with predictions based on mental model theory – confirming H2. Secondly, results from the Test of Conjunctive Bias mirrored the results of Rader and Sloutsky (2001) – confirming H3. These findings

provided construct validity to each test, respectively. Results from Phase 1 supported the hypothesis that ELL students have an incomplete understanding of the truth-functions of English connectives (H4) and that conjunctive bias is present in ELL students (H3).

In Phase 2, results from pre- and post-tests of the Test of Claim Evaluation showed that participants who received explicit instruction in the truth-functions of English connectives had a mean improvement of 19% - a significantly greater increase than the 3% mean improvement found in those who received implicit instruction – supporting H5, H6, and H7. Pairwise comparisons showed the connectives which showed significant improvement among those who received explicit instruction were the inclusive disjunction ‘or’ and the conditional ‘if, then’. The increases in proficiency of ‘or’ were likely due to ELL students ability to form fully explicit models. The increases in proficiency of ‘if, then’ may be due to their ability to lower cognitive load by applying the principle of simplifying models (e.g., if you know that the antecedent of a conditional is false, then can assess it as true without concern for the truth-value of the consequent).

In Phase 3 and 4, it was shown that explicit instruction significantly improved scores of those who had received implicit instruction in Phase 2. In addition to significant increases that mirrored the explicit-instruction group in Phase 2, those who received implicit instruction prior to receiving explicit instruction showed a significant increase of 14% in proficiency level for the exclusive disjunction. However, between-group comparisons in Phase 4 did not show significant differences in proficiency of any connective. Thus, the results support H6 and we can conclude that implicit instruction does not have a significant effect on the proficiency of truth-functional connectives. Furthermore, these results support H5 and H7, and thus we can conclude that explicit instruction in truth functions of English connectives is a significantly effective method of improving the understanding of truth-functions among ELL students (H5) and that

explicit instruction is significantly more effective than implicit instruction in this regard (H7).

Phase 5 showed that explicit instruction in truth-functional connectives had a significant effect on conjunctive bias. Prior to explicit instruction in truth-functional connectives, ELL students were able to discriminate target conjunctions from disjunction foils and conditional foils. They also had difficulty discriminating conjunction foils, from disjunction targets and conditional targets. These two facts fulfill the two conditions of conjunctive bias (See page 74 for a description of the conditions) and confirmed the presence of conjunctive bias in ELL students prior to instruction in truth-functional connectives. As shown in Figure 9, after explicit instruction in truth-functional connectives the hallmarks of conjunctive bias were reversed. Disjunction and conditional targets were accepted significantly more and conjunctive foils were accepted significantly less. That is, the rate at which disjunctions and conditionals were misinterpreted as conjunctions dropped drastically and each were accurately recognized more frequently. Additionally, original conjunctions were accepted as disjunctions 14% less. Thus, following explicit instruction in truth functions, accurate recognition of conjunctions, disjunctions, and conditionals increased along with increased ability to accurately discriminate targets from foils. This confirms and goes beyond the primary hypothesis of this thesis (H1), showing that an increase in knowledge of truth-functional connectives is not only related to a decrease in conjunctive bias, but can eliminate it entirely.

Chapter 7 : Conclusion

7 Conclusion

This work has built upon the significant findings in the literature surrounding CT-interventions over the past 60 years, literature assessing the relationship of logical connectives, comprehension, and production in ELL (See below for more discussion). The insights from the past 60 years of research were applied in this thesis to shape instructional materials and methods to begin to fill the current void in the literature surrounding the link of truth functional knowledge, literacy, and memory.

This study has addressed the primary research question – showing that explicit instruction in truth-functional connectives can eliminate conjunctive bias in ELL students. This research provides a significant link between knowledge of truth-functional connectives and memory – that was not present in the literature before (See contributions below). Supporting this primary question, it has also been shown that, in addition to native English speakers, ELL students suffer from conjunctive bias and have a low to moderate understanding of the truth functions of conjunctions, inclusive and exclusive disjunctions, conditionals, and bi-conditionals. In addition to the findings supporting the use of explicit instruction when teaching logical connectives, this work has identified an area in language learning where instruction is in need and provided the methods to facilitate that instruction (See Pedagogical Implications below).

Chapter 8 : Contributions

8 Contributions

The results of this study are discussed below in terms of the contributions to the research literature and to pedagogy.

8.1 Research Literature

This study has made contributions to the research literature related to conjunctive bias, the relation of conjunctive bias and truth-functional connectives, and through the creation of test forms to measure each.

Confirmation of hypothesis 3 shows that conjunctive bias is present in non-native English speakers. This expands upon the findings of Rader and Sloutsky (2001) who showed that it was present in native English speakers. This further expands support for the phenomenon of conjunctive bias discovered by Rader and Sloutsky (2001). I've also shown, through confirmation of H1, that knowledge of truth-functional connectives is closely tied to our ability to accurately recall sentences that employ these connectives. Up until this point, the literature, based in model theory, has only provided a relation between the complexity of these connectives and our understanding of them (Goodwin & Johnson-Laird, 2011; Johnson-Laird, 2011). The additional understanding brought forth by this thesis expands our knowledge of the implications of knowledge of truth-functions, which has pedagogical implications (see below). Lastly, this thesis has contributed two new forms of The Test of Conjunctive Bias and three forms of the Test of Claim Evaluation. The former are shorter than the original test published by Rader and Sloutsky (2001) providing faster writing times. This is especially important due to the fact that SuperLab 5.0 requires a license on each computer that is used to run the program. Thus, in order to run tests simultaneously, multiple licenses are required. Secondly, the creation

of two test forms allows pre- and post-tests with a reduced risk of practice effects. These tests will allow the further assessment of conjunctive bias, which provides information related to our memory and comprehension of claims, as well as the assessment of our ability to understand, evaluate, and analyse the implications of compound and complex claims. Due to the prevalence of compound and complex claims in English, these are very useful tools for further evaluation of comprehension and proficiency in English – and effects of instruction on comprehension and proficiency.

8.2 Pedagogical Implications

This thesis has several pedagogical and practical implications related to implicit and explicit instruction, critical thinking, ELL's, and the importance of instruction in the truth functions of English connectives. The results related to H7 (that explicit instruction in t-f connectives is significantly more effective than implicit instruction) confirmed the wealth of literature supporting the need for explicit instruction in complex content areas (Abrami et al, 2008; Bangert-Drowns & Bankert, 1990; Angeli & Valenides, 2008; Hunt, 2002). We have shown the negligible impact that implicit instruction has on the understanding of truth-functions and the extremely significant impact that explicit instruction has on our understanding and memory of truth-functional claims.

The instructional exercises were presented using contextual interference – through interleaving practice materials (See Literature Review, p. 29-30, for further information) – and retroactive prompts. Carlson and Yaure (1990) and Helsdingen et al. (2011) showed that these techniques would result in greater transfer of skills to other domains as well as greater long-term recall. The presentation of exercises using these methods in this study reinforced these pedagogical practices by showing the effect that instruction in evaluating compound and complex claims had on memory tasks. These results reinforce the literature supporting the practice of using contextual interference and retroactive

prompts to enhance retention and application of knowledge across domains – which has implications for instruction in all subject areas.

This thesis also provides support for the integration of technology in the classroom. The electronic exercises allowed interleaved instructional content and provided immediate individual feedback (retroactive prompts) to compliment in-class instruction (see page 32 for an explanation of the benefits of these practices). The use of electronic exercises allowed for each student to complete the interleaved exercises at their own pace and receive personalized feedback. This exhibited how useful technology can be in the classroom when used as a support for learning objectives. Following explicit instruction and the completion of exercises with explicit feedback, ELL students' understanding of truth functions significantly increased.

This thesis supported pedagogical research that has showed instruction in formal and informal logic increases CT skills (Abrami et al., 2008; Annis & Annis, 1979; McCarthy-Tucker, 1995). Reflected through their increases in scores on the Test of Claim Evaluation and the elimination of conjunctive bias, the instruction in the truth-functions of English connectives increased ELL students' interpretation, analysis, and evaluation of compound and complex claims. These are skills noted by the American Philosophical Association Delphi panel of 46 experts as being associated with critical thinking (Abrami et al., 2008, p.1103) and facilitate greater comprehension and proficiency in English.

Prior reasons supporting instruction of truth-functions in language and reasoning education were limited to speculation regarding the effects that this knowledge could have on critical thinking and it was generally seen as too abstract to be applicable. However, the current thesis has shown that knowledge of truth functions can also eliminate conjunctive bias. This significantly expands the motivation for instruction in truth functions of English language connectives. Regardless of the impact on CT, the

instruction provided in this thesis has shown an elimination of conjunctive bias and an improvement in the memory of 'or' and 'if, then' statements. This has extensive implications in every realm that involves the use of 'and', 'or', and 'if, then' in sentences – such as increasing ELL students' comprehension and proficiency in English – providing good reason to include truth functions in classroom instruction.

Lastly, the instructional method employed provided a clear and intuitive way to learn the truth functions of English connectives. As has been shown in the literature, ELL students struggle with the overuse, misuse, and misunderstanding of English connectives (Bolton et al., 2002; Chen, 2006; Hinkel, 2002; Ozono & Ito, 2003; Zhang, 2000). Rather than relying solely on the rote memorization of truth tables, the exercises provided students an opportunity to evaluate the conditions that would make statements true or false through real world examples. The exercises and instruction significantly increased ELL students' understanding of these connectives, which is important given their current misunderstanding of them and their importance in comprehension and proficiency in English. Furthermore, by contextualizing truth-functional knowledge in real world examples of our language, the students stayed engaged and got a closer look to how the knowledge of truth functions could be applied to the comprehension of English than they would through the conventional study of truth functions through truth tables, such as the one shown in Table 2 (p. 9). The differences in effects of these methods of instruction (studying truth functions through truth tables as opposed to evaluating them in sentence form) is a question that should be addressed in further research (See Recommendations for Further Research below for further discussion).

Chapter 9 : Limitations

9 Limitations

This study has several limitations. The first is the limited number of participants. Due to the large time commitment to complete the testing and instruction in this study there was a large attrition rate. The number of participants who started in Phase 2 dropped by over half of the initial number upon conclusion of the instruction and testing in all phases. Results were significant, but further research should be conducted with a larger pool of participants (See Recommendations for Further Research below for further discussion).

The second limitation is the length of instruction. As was noted in the discussion above, several effects approached significance – and these effects as well as the size of other effects may be strengthened by increasing the number of instructional lessons. Furthermore, longer instructional sessions would allow for further instruction in the effects of conversational implicature on the interpretation of truth-functional connectives in conversational implicature was beyond the scope of this study, but it plays a very large role in the interpretation of the connectives discussed in this study. The lack of instruction in conversational implicature in this study presents a serious limitation and should be investigated in further research (see Recommendations below for further discussion).

This study did not employ a counterbalanced measures design, which reduces the chance that the order the instruction is provided would negatively influence the results. In this study with two instructional conditions, this would involve providing one group the implicit instruction followed by the explicit instruction and providing the second group the instruction in the opposite order. Implicit instruction participants were also given two

sets of instruction and a third Test of Claim Evaluation compared with the explicit instruction group of phase two. This raises the concern of carry over effects. However, tests were carried out in Phase 3 to assess differences caused by the implicit instruction and no significant results were found. Thus, it is unlikely that the results were significantly negatively skewed by the lack of a counterbalanced measures design or carry over effects.

Conjunctive bias was only tested after both groups had received explicit instruction. Thus, we cannot determine whether implicit instruction has a significant effect on conjunctive bias. However, due to the insignificant impact that implicit instruction had on mean truth functional understanding, it is unlikely that it would have a significant impact on conjunctive bias.

Instructional exercises mirrored the assessment method of the Test of Claim Evaluation. Thus, the instructional phase(s) were teaching to the test. It is possible that participants' ability to solve the questions of the Test of Claim Evaluation improved, but not their understanding of truth-functional connectives. A more complete assessment of their understanding of truth-functional connectives could be assessed through additional measures. A related issue concerns the lack of qualitative assessment. In-person interviews or questionnaires could be used to receive further insight into the gains of participants and their thoughts and personal perspectives surrounding instruction and instructional effects (See Recommendations for further discussion).

Lastly, it is possible that implicit instruction would have a significant and positive effect over a longer instructional period. By limiting the implicit instruction to four hours this experiment was unable to measure whether or not long-term implicit instruction would have a positive effect on knowledge of truth functions or the elimination of conjunctive bias.

Chapter 10 : Recommendations for Future Research

10 Recommendations for Future Research

There are several recommendations for future research to be made – some directly related to the limitations of this study and stemming from the strengths of the findings. Concerning the former, similar work should be conducted with a larger sample of participants and more instructional time. The increase in number of participants will provide more strength to the participants and – coupled with greater instructional time – will likely flesh out effects that only approached significance. With an increase in instructional time, more time can be spent on the connectives covered as well as other connectives and their various forms (e.g., ‘if and only if’, ‘and’, ‘unless’, and ‘if’). Additionally, assessment of the effects of instruction in truth-functional connectives could be further understood through the use of qualitative interviews or questionnaires. These measures could be used to shed light on the differences in learners’ mental models before and after instruction as well as their perceptions of how this knowledge may benefit them.

Results in Phase 4 showed that the group who received *both* implicit and explicit instruction had a worse understanding of ‘or’ ($p = .06$) than the group who only received explicit instruction. Although the difference only approached significance, this finding prompts the question: is implicit instruction in truth functions detrimental to understanding of truth functions? Without explicit instruction and feedback learners may create their own incorrect or incomplete rules – which in turn may impede their future understanding. To examine this question, it would be beneficial to complete a study, similar to this thesis, with more instructional time and a counterbalanced measures design. The increased instructional time will increase the likelihood of finding significant

effects, if there are any, and show whether receiving implicit instruction will lead to significant misunderstanding if it is provided before or after explicit instruction.

As noted above, the provided instruction - by contextualizing truth-functional knowledge in real world examples of our language rather than studying truth tables – may be more easily applied to areas outside of formal logic such as reading, writing, understanding conversational implicature, and reasoning. Further research should be conducted to assess the effect of instruction in the truth functions of English connectives on the understanding and interpretation of conversational implicature. As discussed in the Literature Review (p. 17-23) conversational implicature has an extremely important role to play in the interpretation of truth-functional connectives in natural language. Research on the effects of its t-f instruction opens up an avenue of further areas of interest, such as: the relationship between knowledge of conversational implicature and the ability to accurately identify and understand the intended meaning in narrative, descriptive, persuasive, and expository text or speech; the ability to identify the use of exploitations of conversational implicature in narrative, descriptive, persuasive, and expository text and speech; and the assessment of whether instruction in truth-functions facilitates the inclusion compound and complex sentences in writing. Furthermore, due to the presence of truth-functional connectives in statements included in argumentation, understanding of these connectives may facilitate the accurate analysis and appraisal of arguments.

References

- Abrami, P. C., Bernard, R. M., Borokhovski, E., Wade, A., Surkes, M. A., Tamim, R., & Zhang, D. (2008). Instructional interventions affecting critical thinking skills and dispositions: A stage 1 meta-analysis. *Review of Educational Research, 78*, 1102-1134. doi: 10.3102/0034654308326084
- Angeli, C., & Valanides, N. (2009). Instructional effects on critical thinking: Performance on ill-defined issues. *Learning and Instruction, 19*, 322-334. doi: 10.1016/j.learninstruc.2008.06.010
- Annis, L. F., & Annis, D. B. (1979). The impact of philosophy on students' critical thinking ability. *Contemporary Educational Psychology, 4*, 219-226.
- Bangert-Drowns, R.L. & Bankert, E. (1990). *Meta-analysis of effects of explicit instruction for critical thinking*. Albany, NY: State University of New York.
- Blair, J. (1990). Reasoning and literacy. In S. Norris & L. Phillips (Eds.), *Foundations of literacy policy in Canada* (pp. 69-84). Calgary, AB: Detselig Enterprises Ltd.
- Bolton, K., Nelson, G., & Hung, J. (2002). A corpus-based study of connectors in student writing: Research from the international corpus of English in Hong Kong (ICE-HK). *International Journal of Corpus Linguistics, 7*, 165-182.
- Broukal, M. (2008). *Grammar form and function level 2*. (2 ed., pp. 320). New York, NY: McGraw-Hill
- Brunstein, J.C. & Glaser, C. (2011). Testing a path-analytic mediation model of how self-regulated writing strategies improve fourth graders' composition skills: A

randomized controlled trial. *Journal of Educational Psychology*, 103, 922-938.
doi: 10.1037/a0024622

Carlson, R.A., & Yaure, R.G. (1990). Practice schedules and the use of component skills in problem solving. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 16, 484-496.

Chaudron, C. & Richards, J.C. (1986). The effect of discourse markers on the comprehension of lectures. *Applied Linguistics*, 7, 113-127.

Chen, C. W. (2006). The use of conjunctive adverbials in the academic papers of advanced Taiwanese EFL learners. *International Journal of Corpus Linguistics*, 11, 113-130.

Chung, J.S.L. (2000). Signals and reading comprehension: theory and practice. *System*, 28, 247-259.

Cohen, L., Manion, L., & Morrison, K. (2011). *Research methods in education*. (7 ed., pp. 31-37). New York, NY: Routledge.

Dam, G., & Volman, M. (2004). Critical thinking as a citizenship competence: Teaching strategies. *Learning and Instruction*, 14, 359-379. doi: 10.1016/j.learninstruc.2004.01.005

Goldman, S.R. and Murray, J.D. (1992). Knowledge of connectors as cohesion devices in text: A comparative study of native-English and English-as-a-second-language speakers. *Journal of Educational Psychology*, 84, 504-519.

Goodwin, G.P. and Johnson-Laird, P.N. (2011). Mental models of Boolean concepts. *Cognitive Psychology*, 63, 34-59.

- Grice, H. P. (1975). Logic and conversation. In Cole, P. and Morgan, J.L. (Eds.), *Syntax and semantics 3: Speech acts* (41-58). New York: Academic Press.
- Grice, H. P. (1989). *Studies in the way of words*. Cambridge, Mass: Harvard University Press.
- Haberlandt, K. (1982). Reader expectations in text comprehension. In J.F. Le Ny & W. Kintsch, (Eds.), *Language and comprehension* (pp. 239-249). Amsterdam: North-Holland.
- Helsdingen, A., Gog, T.V., & Merrienboer, J.V. (2011). The effects of practice schedule and critical thinking prompts on learning and transfer of a complex judgment task. *Journal of Educational Psychology*, 103, 383-398. doi: 10.1037/a0022370
- Hinkel, E. (2002). *Second language writers' text: Linguistic and rhetorical features*. Mahwah, NJ: Lawrence Erlbaum.
- Hunt, C.A. (2002). *Promoting critical thinking: An analysis of instructional techniques with undergraduates in a university setting*. Manhattan, KS: Department of Foundations and Adult Education, Kansas State University.
- Hyslop-Margison, E.J., Pinto, L. (2007). Critical literacy for democratic learning in career education. *Canadian Journal of Education*, 30, 193-210.
- Johnson-Laird, P. N. (2001). Mental models and deduction. *Trends in Cognitive Sciences*, 5, 434 – 442.
- Johnson-Laird, P. N. (2013). Mental models and cognitive change. *Journal of Cognitive Psychology*, 25, 131 – 138.

- Jung, E.H. (2003). The role of discourse signaling cues in second language listening comprehension. *Modern Language Journal*, 87, 562-577.
- Jung, E.H. (2006). Misunderstanding of academic monologues by non-native speakers of English. *Journal of Pragmatics*, 38, 1928-1942.
- Klein, P., Olson, D. R., & Stanovich, K. (1997). Structuring reflection: Teaching argument concepts and strategies enhances critical thinking. *Canadian Journal of School Psychology*, 13, 38-47. doi: 10.1177/082957359701300104
- Loman, N.L. & Mayer, R.E. (1983). Signaling techniques that increase the understandability of expository prose. *Journal of Educational Psychology*, 75, 402-412.
- McCarthy-Tucker, S.N, (1995). *Teaching reality-based formal logic to adolescents to improve critical thinking skills*. Tempe, AZ: Arizona State University
- McKeown, M.G., & Beck, I.L. (2009). The role of metacognition in understanding and supporting reading comprehension. In D.J. Hacker, J. Dunlosky, & A.C. Graesser (Eds.), *Handbook of metacognition in education* (pp. 7-25). New York, NY: Routledge
- Millis, K.K. & Just, M.A. (1994). The influence of connectives on sentence comprehension. *English for Specific Purposes*, 9, 33-47.
- Ozono, S. (2002). An empirical study on the effects of logical connectives in EFL reading comprehension. *Annual Review of English Language Education in Japan*, 13, 61-70.

- Ozono, S. & Ito, H. (2003). Logical connectives as catalysts for interactive L2 reading. *System* 31, 283-297
- Pretorius, E.J. (2006). The comprehension of logical relations in expository texts by students who study through the medium of ESL. *System*, 34, 432-450.
- Rader, A. & Sloutsky, V. (2001). Conjunctive bias in memory representations of logical connectives. *Memory & Cognition*, 29, 838-849.
- Sanders, T.J.M. & Noorman, L.G.M. (2000). The role of coherence relations and their linguistic markers in text processing. *Discourse Processes*, 29, 37-60.
- Vasiljevic, Z. (2013). Assessing learners' comprehension of logical connectives in L2 texts. *Theory and Practice in Language Studies*, 3, 7-16. doi:10.4304/tpls.3.1.7-16
- Zhang, M. (2000). Cohesive features in the expository writing of undergraduates in two Chinese universities. *RELC Journal*, 31, 61-95.

Appendix A

Sample Item from the Test of Claim Evaluation

Select *each* answer that will make the following statement TRUE. Note: There may be multiple answers that will make the statement true.

If Artem is in a bar, then he is at least 19 years old.

- Artem is in a bar and is 17 years old.
- Artem is in a bar and is 20 years old.
- Artem is not in a bar and is 18 years old.
- Artem is not in a bar and is 24 years old.

Appendix B

Sample Implicit Instruction Item

This is an "OR" claim. An "OR" claim is a statement made of two or more claims that are joined by "OR".

Select the answer that will make the statement TRUE. Note: There may be more than one correct answer.

Kat likes the sun or loves water.

- Kat loves water and hates the sun. (0.5 points) ◆
- Kat likes the sun. (0.5 points) ◆
- Kat likes summer. (-0.5 points)
- None of the above. (-0.5 points)

(1 points)

Out of a possible 1, you scored 0

This "OR" claim has two parts:

-Kitty likes the sun

-Kitty loves the water

The fact that kitty likes summer is irrelevant to the truth or falsity of the disjunctive claim

Note: Red signifies the incorrect answers and blue signifies the correct answers.

Appendix C

Sample Explicit Instruction Item

This is an "OR" claim. An "OR" claim is a statement made of two or more claims that are joined by "OR".

An "OR" claim is true if one or more of the claims it joins is true.
An "OR" claim is false only if ALL of the claims it joins are false.

Select the answer that will make the statement TRUE. Note: There may be more than one correct answer.

Kat likes the sun or loves water.

- Kat loves water and hates the sun. ♦
- Kat likes the sun. ♦
- Kat likes summer.
- None of the above.

Out of a possible 1, you scored 0
Incorrect

This "OR" statement is made of two claims:

- Kitty likes the sun
- Kitty loves the water

Only one of those parts needs to be true for the "OR" claim to be true. The first two options (A & B) make one of those parts true.

The fact that kitty likes summer does not make "Kitty likes the sun or loves water" true.

Note: Red signifies the incorrect answers and blue signifies the correct answers.

Appendix D

Original Propositions for Test of Conjunctive Bias Form A

No.	Conjunctions*	Disjunctions*	Conditionals ^v
1	Takes medicine and he likes the zoo	Writes letters or he eats potatoes	If ... plays baseball then he is a secretary
2	Trains dolphins and he breaks bread	Repairs dishwashers or he collects stamps	If ... grows flowers then he misses the ocean
3	Goes fishing and he wears shoes	Hates dentists or he uses a typewriter	If ... mows the grass then he loves the beach
4	Breaks pencils and he likes apples	Helps strangers or he calls his parents	If ... hears records then he swims the river
5	Has nightmares and he breaks speed limits	Runs a company or he goes camping	If ... climbs mountains then he places bets
6	Fears snakes and he coaches soccer	Sells cars or he avoids butter	If ... watches TV then he rides horses
7	Irons his clothes and he cleans the shower	Teaches school or he fails physicals	If ... forgets birthdays then he listens to songs
8	Has children and he shaves his beard	Reads poetry or he clips coupons	If ... drinks tea then he burns trash
9	Teaches history and he spends money	Sings hymns or he rakes leaves	If ... eats salads then he settles disputes
10	Drinks beer and he builds houses	Reads newspapers or he joins clubs	If ... cleans his office then he wears spectacles

*Each description began with *This professor* (omitted from table entries for brevity).

^vThe phrase *this professor* followed "If" in each description (omitted for brevity).

(Rader & Sloutsky, 2001, p. 849)

Appendix E

Original Propositions for Test of Conjunctive Bias Form B

No.	Conjunctions*	Disjunctions*	Conditionals ^v
1	Attends school and he likes hotels	Grows corn or he tells jokes	If ... demands perfection then he collects wine
2	Buys insurance and he watches birds	Plays boardgames or he goes to the movies	If ... tells lies then he follows others
3	Combs his hair and he edits a newspaper	Sleeps all day or he buys paintings	If ... has a cat then he eats pizza
4	Designs houses and he writes letters	Helps friends or he builds tables	If ... grows vegetables then he owns a house
5	Skips meetings and he wears polyester	States his opinions or he uses maps	If ... makes dinner then he rides a bicycle
6	Takes breaks and he likes corn	Writes books or he rides bikes	If ... plays hockey then he is a manager
7	Trains mice and he lifts weights	Repairs chimneys or he drinks coffee	If ... grows a moustache then he misses the mountains
8	Goes skiing and he wears gloves	Hates lawyers or he uses a pencil	If ... paints then he loves the country
9	Breaks windows and he likes jazz	Helps animals or he calls his friends	If ...hears music then he swims the river
10	Has acne and he likes fish	Runs a factory or he goes travelling	If ...climbs trees then he cooks spinach

*Each description began with *This professor* (omitted from table entries for brevity).

^vThe phrase *this professor* followed "If" in each description (omitted for brevity).
(Rader & Sloutsky, 2001, p. 849)

Appendix F



Research Ethics

Western University Health Science Research Ethics Board
NMREB Delegated Initial Approval Notice

Principal Investigator: Dr. Steve Bird
Department & Institution: Education, Western University

NMREB File Number: 106419
Study Title: An Empirical Investigation on Conjunctive Bias and Instruction in Logical Connectives with English Language Learners
Sponsor:

NMREB Initial Approval Date: March 30, 2015
NMREB Expiry Date: March 30, 2016

Documents Approved and/or Received for Information:

Document Name	Comments	Version Date
Revised Western University Protocol	Clean Western Protocol	2015/03/19
Revised Letter of Information & Consent	Clean Letter of Information	2015/03/19
Instruments	Instrument Sample	2015/01/09
Instruments	Exercise Sample	2015/01/09

The Western University Non-Medical Research Ethics Board (NMREB) has reviewed and approved the above named study, as of the NMREB Initial Approval Date noted above.

NMREB approval for this study remains valid until the NMREB Expiry Date noted above, conditional to timely submission and acceptance of NMREB Continuing Ethics Review.

The Western University NMREB operates in compliance with the Tri-Council Policy Statement Ethical Conduct for Research Involving Humans (TCPS2), the Ontario Personal Health Information Protection Act (PHIPA, 2004), and the applicable laws and regulations of Ontario.

Members of the NMREB who are named as Investigators in research studies do not participate in discussions related to, nor vote on such studies when they are presented to the REB.

The NMREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000941.

Ethics Officer, on behalf of Riley Hinson, NMREB Chair or delegated board member

Ethics Officer to Contact for Further Information

Erika Basile ebasile@uwo.ca	Grace Kelly grace.kelly@uwo.ca	Mina Mekhal mmekhal@uwo.ca	Vikki Tran vikki.tran@uwo.ca
--------------------------------	-----------------------------------	-------------------------------	---------------------------------

This is an official document. Please retain the original in your files.

Curriculum Vitae

Name: Eric Smiley

Post-secondary Education and Degrees: University of Guelph
Guelph, Ontario, Canada
2009-2013 B.A.H.

The University of Western Ontario
London, Ontario, Canada
2013-2016 M.A.

Honours and Awards: Learning Enhancement Fund
2013

Western Graduate Research Scholarship
2014 and 2015

Related Work Experience

Undergraduate Research Assistant
University of Guelph
2012 - 2013

Graduate Research Assistant
The University of Western Ontario
2013-2016

Graduate Research Assistant
Grand Erie District School Board
2015-2016

Graduate Research Assistant
Avon Maitland District School Board
2015-2016

Presentations:

Searle, M., Kirkpatrick, L., Sauder, A., Smiley, E., & Henshaw, M. (2016). *Educational Innovation Through the Use of a Collaborative Impact Research of a One-to-One Device Project*. Canadian Society for the Study of Education (CSSE), University of Calgary, Calgary, Alberta.

Smiley, E. (2014). *Logic in Context: Using Logic to Improve Critical and Literacy Skills*. Canada International Conference in Education. Cape Breton University, Cape Breton, Nova Scotia.

Smiley, E. (2014). *Logic in Context: Teaching Logic with Language and Improving Critical Literacy Skills*. Robert MacMillan Graduate Research in Education Symposium (GRiES). University of Western Ontario, London, Ontario.