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Creativity in Two Languages: Convergent and Divergent Thinking in Bilingual Engineering Students

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ABSTRACT

In our modern globalized society, more than half of the world's population is bilingual (Grosjean, 2010), and, as a result, more companies are expecting employees to be able to communicate professionally across languages when conducting business in global markets. Recent research has also indicated that being bilingual enhances creative thinking and problem-solving skills (Rodriguez-Fornells, 2011; Lee and Kim, 2011; Ricciardelli, 1992).

There are two types of thinking associated with problem-solving: convergent and divergent thinking. Convergent thinking is used when there is one specific correct answer to a problem, while divergent thinking is used to solve abstract problems with multiple solutions. A study conducted by Hommel et al. (2011) investigated low- and high-proficient bilinguals in their second language (L2) and how their proficiency impacted convergent and divergent thinking abilities in their first language (L1). The study, however, failed to not compare bilinguals' thinking abilities across languages. It is very important for bilinguals to be able to solve problems in both their L1 and L2, especially when it comes to working in the engineering field, as they heavily rely on creative problem-solving skills for success and innovation.

To the best of my knowledge, there has been no research studies that have compared how bilinguals think and solve problems in their L1 compared to their L2. This present study aims to answer two major questions associated with thinking abilities across languages: how convergent and divergent thinking abilities are affected by language (L1 vs. L2), and to what extent prior problem-solving activities in the L2 affect convergent and divergent thinking in the L1 and L2.

To perform this study, thirty-two German-English bilinguals pursuing an engineering major at the Technische Universität Braunschweig and indicating German as their L1 were recruited. Participants first participated in an interactive, real-life, engineering problem-solving

task, where they generated as many solutions to the problem as they could in their L2. The participants then performed the convergent (RAT) and divergent (AUT) thinking tasks in various orders to assess the impact that the interactive problem-solving task in their L2 had on their performance in the task immediately following this. Finally, participants completed the LexTALE (Lemhöfer & Broersma, 2012) vocabulary task to assess their vocabulary skills in both their L1 and L2, and a Language History Questionnaire.

Data analysis showed a significant main effect of language on convergent thinking abilities (RAT), but no significant effect of language on creativity scores related to divergent thinking abilities (AUT). This means that language proficiency and vocabulary knowledge in the L1 or L2 significantly impacts convergent thinking abilities, but does not impact divergent thinking abilities. Language did, however, impact the participants' fluency scores on the AUT. This result indicates that the semantic network, which is where an individuals' creative thinking abilities stem from and has been proven by Borodkin et al. (2016) to be less-organized in an individuals' L2 compared to their L1, impacts the quantity of creative ideas generated but does not affect the quality of ideas. Finally, the correlation results indicated that there was no significant interaction between language and language order on divergent and convergent thinking abilities, meaning that there was no effect of having participants solve the interactive real-life problem in their L2 before completing either the divergent (AUT) or convergent (RAT) thinking task in their L2.

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Chapter 1: Introduction

Within the past few decades, our society has made a huge shift towards globalization, making interactions between individuals from different languages and cultures unavoidable and resulting in an increase in bilingualism worldwide. In the past, individuals would learn multiple languages if they needed it for a job or if they were moving to another country that did not speak their native tongue. In our modern globalized world however, there is an increased need to speak multiple languages, as many companies expect employees to be able to work and conduct business in global markets. Today, the number of bilinguals is continuing to increase and more than half of the world's population is bilingual (Grosjean, 2010).

With bilingualism being so prominent in our everyday lives, it is important for us to study and compare how bilinguals think in each of their languages. In the past, there have been many studies comparing the way that bilinguals and monolinguals think. From these studies, bilinguals have been found to outperform monolinguals in problem solving (Bain, 1975), perceptual focusing (Duncan & De Avila, 1979), and cognitive flexibility (Bialystok & Viswanathan, 2009), while monolinguals have been found to outperform bilinguals in verbal fluency tasks (Rosselli et al., 2000; Gollan et al., 2002) and verbal creativity (Kharkhurin, 2010). Additionally, there have been several studies that have shown an overall bilingual advantage in executive functions, which directly correlates with creativity (Bialystok & Majumder, 1998; Costa et al., 2008). However, with over half the world's population being bilingual and bilingualism therefore becoming the new "norm" in our modern society, it is important to assess and compare the ways that bilinguals think in their first language (L1) vs. their second language (L2), especially in terms of their creative thinking potential.

1.1 The Need for Bilinguals to Think Creatively in Both Languages

Creativity is becoming an increasingly important competitive tool for innovation, problem solving, and success in our rapidly changing technology-oriented world. Today, we are under a lot of pressure and are dealing with a lot of demands to change and improve, making innovation and creativity the key to survival and success. A study performed by Ann Roe et al. (1953) on the characteristics of people with recognizable creativity concluded that creative individuals had more motivational characteristics, were more interested in esthetic and theoretical matters, and tended to be highly intuitive. Guilford (1967), an esteemed American psychologist well known for his psychometric study of human intelligence, explains that the solution to the plethora of human problems that we face today are creative problem-solving people who are well-informed and have skills in using information efficiently. Guilford (1967) considered these the characteristics of individuals who will be able to innovate and improve our modern society. There has never before been a world population of more informed and educated individuals, however the ability for these individuals to be able to use their knowledge to solve problems is dependent on their creative potential and production.

It is particularly important for bilinguals to be able to think creatively in both their L1 and L2, as they will be using both of these languages when solving problems and innovating in the corporate world. Rodriguez-Fornells et al. (2011) performed a study on 38 Finnish-Swedish bilinguals and found that overtime, bilingualism and the constant cognitive monitoring of potential competition between their language systems enhances creative thinking. Other studies came to the same conclusion, that bilingualism improves creativity (Lee and Kim, 2011; Ricciardelli, 1992), but some findings have led to the opposite conclusion, that bilingualism worsens creativity (Hommel, Colzano, Fischer, & Christoffels, 2011). Creative potential,

however, has never been tested in, and compared across, bilinguals' two languages. When assessing creative thinking skills of bilinguals, it is important to assess this in both their first (L1) and second (L2) languages. Therefore, my study investigated and compared the creative potential and ways of thinking of bilinguals in both their L1 and L2.

1.2 A Breakdown of Convergent and Divergent Thinking in Bilinguals

Problem solving has been associated with two types of thinking: convergent thinking and divergent thinking. These concepts were both introduced by Guilford (1967) and are considered a classic yet still highly active research field in cognitive psychology. Convergent thinking is used when there is a well-defined, straightforward, correct answer to a problem. Divergent thinking, on the other hand, is used when solving an abstract problem that has many possible solutions. To the best of my knowledge, Hommel, Colzano, Fischer, and Christoffels (2011) conducted the first and so far, only study that examined both divergent and convergent thinking in bilinguals, and the extent to which variation in L2 proficiency influenced divergent and convergent thinking outcomes.

Hommel et al. (2011) tested adult Dutch-English bilinguals with high levels of L2 English proficiency and German-English bilinguals with lower levels of L2 English proficiency. They completed divergent and convergent thinking tasks that are commonly used in this literature in their L1 Dutch: the Alternate Uses Task (AUT, for divergent thinking; Guilford, 1967) and the Remote Associates Task (RAT, for convergent thinking; Mednick, 1962).

In the Alternate Uses Task, participants are asked to name as many unusual or original uses for a series of common objects (e.g., brick). The results are commonly scored regarding the number of responses (fluency), the number of different categories being used (flexibility), the

degree to which the responses differ from the standard or group mean (originality), and the amount of detail (elaboration). In the Remote Associates Task, participants are presented with three concepts, for example ‘hair,’ ‘stretch,’ and ‘time,’ and are asked to identify the one concept that fits with all three terms (here: ‘long’). Hommel et al. (2011) found that the low-proficient bilinguals showed better performance on the divergent thinking task, while the high-proficient bilinguals excelled in the convergent thinking task. This is an unexpected finding in light of Kharkurin’s (2012) study reporting that bilinguals tend to outperform monolinguals on creative thinking tasks (so high-proficient bilinguals were expected to perform better on the divergent thinking task). Unfortunately, Hommel et al. (2011) did not administer the tasks in the bilinguals’ L2, so we do not know how L1 performance would relate to L2 performance, and how variation in L2 proficiency impacts performance.

As previously stated, it is important for bilinguals to think creatively in both their L1 and L2, if they wish to innovate and succeed in their careers and improve our modern society. To the best of my knowledge, no studies have compared divergent and convergent thinking in bilinguals’ L1 and L2 using the Alternate Uses and Remote Associates Tasks. For this reason, I decided to use the same divergent and convergent thinking tasks (AUT and RAT) in my study that Hommel et al. (2011) used, but to administer it in both the participants’ L1 and L2 so that divergent and convergent thinking abilities, and any differences between the two, could be compared across languages.

1.3 Bilingual Engineers and the Importance of Improving their Creativity

As an Engineering major myself, I have found that the most important skills to have to become a successful Engineer is being able to implement and utilize both convergent and

divergent thinking on a daily basis. Typically, engineers need to be able to use their creative potential to come up with ideas, which is why, today especially, this is considered an essential skill for employers when hiring. In our global society, students interested in STEM fields need to be able to thrive in an international setting, and many will work in an international, professional environment where English is the main language of communication. To illustrate, many German employers have changed their working language to English, including Volkswagen, the major employer (and largest industrial site) in the Braunschweig area. This implies that bilingual engineers who are non-native speakers of English often have to think creatively and solve problems in their L2 English.

Despite the need for creative thinking in Engineers, the Engineering education system still tends to emphasize convergent thinking skills rather than divergent thinking skills (e.g., Stouffer, Russell, & Olivia, 2004). Industrial and academic leaders long expressed concerns about the impact of traditional engineering education on the divergent thinking and creative potential for future engineers (Klukken, Parsons, & Columbus, 1997). Osborn and Parnes, founders of the Creative Problem-Solving Institute, partnered up to craft a book entitled *Visionizing* that notes the importance of divergent thinking for personal development and our society at large. The authors emphasize how limited convergent thinking is, especially when attempting to find a single solution from a previous invention or idea. Enhanced insight into divergent and convergent thinking in bilingual engineering students' L1 and L2 can inform education to foster divergent thinking and creativity problem solving in future engineers, essential for the innovative economy of the 21st century.

1.4 Current Study: Research Questions and Hypothesis

Testing engineering students, this project will provide further insights into engineering bilinguals' divergent and convergent thinking skills in their L2 relative to their L1, and how these skills may be affected by prior, small-group and interactive, problem-solving in their L2 (mimicking a professional engineering context). This brings us to the two main questions that will be tested during this study:

1. How is divergent and convergent thinking of an individual affected by the language that they think in (i.e., L1 vs. L2)?
2. To what extent do prior problem-solving activities in the L2 influence later divergent and convergent thinking in the L1 and L2?

Many bilingual engineers will work in an environment where L2 English is the language of communication. To mimic this situation and investigate how being immersed in L2 problem-solving activity hinders or helps bilinguals' subsequent divergent and convergent thinking in L2 and L1, participants will engage in a problem-solving task in their L2 before completing the Alternative Uses Task to assess divergent thinking and the Remote Associate's Task to assess convergent thinking in their two languages.

I predict that for the divergent thinking task (AUT), there will not be much of a difference between the participants' performance in their L1, German, vs. their L2, English. Because the Alternative Uses Task is open ended, the participant can get around lacking a specific L2 vocabulary word they intended to use by using another word with a similar meaning to get their point across. The convergent thinking task (RAT), on the other hand, is very dependent on the participants' vocabulary, as each of the problems corresponds to one specific vocabulary word that counts as the correct answer. Therefore, I predict that for the convergent thinking task, there

will be a difference between the participants' performance in their L1 vs. their L2. Finally, when it comes to prior problem solving and its impact on the participants' performance, this study had the participants solve a real-world engineering problem in their L2, English, prior to completing the convergent and divergent thinking tasks in their L1 and L2. Because this task allows the participants to warm up in their L2, English, I predict that if the participants perform either of the tasks (RAT or AUT) in their L2 right after completing the real-world engineering problem, they will perform better in that specific task than participants who did not conduct the L2 real-world engineering problem task before completing the RAT or AUT in their L2.

Chapter 2: Methods

2.1 Participants

Thirty-nine German-English bilinguals were recruited. All participants pursued an engineering major at the Technische Universität Braunschweig, indicated German as their mother tongue, (i.e., first language, L1) and had good to very good L2 English language proficiency. Their German and English language proficiency levels were measured using LexTALE task (Lemhöfer & Broersma, 2012). Eleven of these participants were recruited via the University's Student Dashboard that is sent out and checked regularly by the entire student population. Sixteen participants were recruited via various Facebook groups, such as TU Braunschweig, which had all the students attending the University in it, and Braunschweig für Ingenieure (Brunswick for Engineers), which had most of the engineering majors attending the University. The remaining twelve were found by word-of-mouth from connections with teachers and students I made while working at the University.

The data from seven out of the thirty-nine participants was excluded: four participants skipped or accidentally missed words in the AUT task, two were noncompliant to the instructions of the AUT task and gave free associations for the objects rather than creative uses, and one participant was mumbling and very difficult to understand in the recordings. Therefore, the analyses presented in this study are based on the remaining thirty-two participants (Mean age = 24.06, *SD* = 3.35). The majority of the participants were right-handed, with only four of the thirty-two reporting to be left-handed. Four of the thirty-two participants were female, while the rest were male. The participants also all reported to have normal or corrected-to-normal vision, no neurological impairment, and no language disorders.

2.2 Materials

2.2.1 Interactive problem-solving task in English

The interactive problem-solving task was a real-life traffic light problem (Hernandez et al., 2013), in English, as follows. Many cities are switching to LED bulbs in their traffic lights. This saves money and conserves energy, but the bulbs do not burn hot enough during major snowstorms to melt off the snow. Participants were asked to think of different ways to solve this problem in the interaction with the experimenter. They were given some time after reading the problem to brainstorm some ideas before they voiced their ideas. This particular approach was taken because it mimics the situation many bilingual engineers will encounter in their profession: conversing with others, thinking creatively, and solving problems in their L2.

2.2.2 Divergent Thinking Task (AUT)

Divergent thinking was assessed with the Alternative Uses Task (based on Guilford, 1967, and translated into German and English). Items were presented individually and participants were asked to mention as many creative uses as possible for each item. The AUT consisted of 8 German items and 8 English items (see Table 1). A total of sixteen items were used to generate two lists for each language (8 items for the English AUT and 8 items for the German AUT). Some participants were tasked to perform the AUT in English using the first eight items (English AUT List 1) and in German using the last eight items (German AUT List 2), while others were presented with the items in the opposite way (English AUT List 2 and German AUT List 1). The participants were given three minutes to generate creative uses for each of the 16 items presented to them.

Originality / creativity scores were obtained via uniqueness scoring for each generated use of the items in the AUT. The raters were first trained and instructed to get a general overview of the ideas mentioned by participants before beginning to rate them. They were then instructed to rate the ideas on a scale of 0-3, with 3 given to ideas that were very creative, uncommon, and novel, and 0 given to ideas that were not creative at all and were very common or senseless (see Table 2 for detailed information on the 4-point scoring scale). Five German-English bilingual raters were recruited and their scores were averaged based on the participant that proposed these creative uses.

Furthermore, fluency scores (a count variable referring to the quantity of ideas generated by a participant) were assigned to each participant. This score was counted, averaged, and compared across all items.

2.2.3 Convergent Thinking Task (RAT)

The Remote Associates Task (based on Mednick, 1962, and translated into German and English) consisted of 30 German items and 30 English items (see Table 3 for German triplets and Table 4 for English triplets). Participants were presented with each triplet (e.g., ‘time,’ ‘hair,’ and ‘stretch’) and had to find a concept that fit with all three (here: ‘long’) within 30 seconds. When selecting the English (Bowden & Jung-Beeman, 2003) and German (Landmann, 2014) triplets, I made sure that none of the triplets overlapped across languages and that they were not too difficult for the participants to solve. This task was scored based on accuracy in the participants’ responses, as there was only one correct answer to each triplet in the Remote Associates Task.

2.2.4 English and German Vocabulary Tasks – LexTALE Task

The LexTALE Task (Lemhöfer & Broersma, 2012) is a simple, non-speeded, visual, lexical decision task that was used to assess the participants' vocabulary proficiency in their L1, German, and their L2, English. The participants were given instructions at the beginning of the task. Both the German and the English lexical decision task consisted of 60 trials, in which participants were presented with a row of letters. Participants were tasked to decide whether the series of letters was an existing word or not (a word in German for the German task and in English for the English task; see Table 5 for German words used and Table 6 for English words used). All instructions during the task were given in the language that the participant was performing the task in. The accuracy of their responses in the German and the English tasks was scored separately and expressed in terms of percentage of correct answers.

2.3 Procedure and Design

This experiment consisted of a single session that was approximately 1.5 to 2 hours in length. After consenting to participate in the experiment, all participants were first instructed to complete the interactive traffic light problem in their L2, where they interacted with the experimenter (myself) and came up with as many possible solutions to the problem. The participants were presented the problem to read and given some time to come up with solutions to the problem prior to presenting them to me. The participants then presented ideas until they could not come up with any more. The entire problem-solving session of each participant was recorded.

Each participant then performed the convergent (RAT) and divergent (AUT) thinking tasks, in one of the following orders:

1. English AUT List 1 → English RAT → German AUT List 2 → German RAT
2. English AUT List 2 → English RAT → German AUT List 1 → German RAT
3. English RAT → English AUT List 1 → German RAT → German AUT List 2
4. English RAT → English AUT List 2 → German RAT → German AUT List 1
5. German AUT List 1 → German RAT → English AUT List 2→ English RAT
6. German AUT List 2 → German RAT → English AUT List 1→ English RAT
7. German RAT → German AUT List 1→ English RAT → English AUT List 2
8. German RAT → German AUT List 2 → English RAT → English AUT List 1

The order of the tasks was varied so that I could assess the impact this problem-solving task in their L2 had on their performance in the task immediately following it in their L1 and/or L2.

Next, participants completed the LexTALE (Lemhöfer & Broersma, 2012) vocabulary task to assess their vocabulary skills in both their L1 and L2. Participants who ended their RAT/AUT tasks in German did the German LexTALE first and vice versa. After the completion of these tasks, participants were asked to fill out a Language History Questionnaire, and were debriefed and paid.

Chapter 3: Results

3.1 Alternative Uses Task: Creativity Scores

The alternative uses that the participants gave for each object were first transcribed by native speakers of English (for the English AUT) and German (for the German AUT). The responses were subsequently rated by 5 bilingual raters. Raters were instructed to first read all of the creative use ideas participants came up prior to rating the ideas to get a sense of which uses were common and not creative and which were uncommon and creative. Raters were then instructed to give each generated idea a score based on how creative, novel, and clever the idea was. The rating scale went from 0, which was given to completely uncreative, common, or senseless ideas, to 3, which was given to creative, original, and sensible ideas. These scores were then averaged for each participant across all items, resulting in five average rating scores per participant for each of the five raters. These five average scores were then averaged again to generate one overall average rating score per participant, which were then put into an excel sheet and used in the ANOVA analysis.

To test for differences in AUT performance in L1 German and L2 English, and whether language order impacted this performance (German AUT task first or English AUT task first), I conducted an ANOVA. Scores from the AUT were subjected to an ANOVA with a within-subject variable of Language (English L2, and German L1) and a between-subject variable of Language Order (German First, English First). These average scores (and SDs) are presented in Table 7.

Table 7: Mean Creativity Scores (and Standard Deviation, SDs) on the German and English AUTs for each of the two Language Order Conditions

Language Order	Language	Mean	SD
English First	German AUT	0.793	0.327
English First	English AUT	0.660	0.240
German First	German AUT	0.820	0.277
German First	English AUT	0.768	0.297

The ANOVA revealed a marginally significant main effect of language, $F(1,30) = 3.387$, $p = .076$, but no significant main effect of language order, $F(1,30) = 0.586$, $p = .450$. As can be seen in Table 7, participants performed slightly better on the AUT task in their L1 German than their L2 English. There was no significant interaction between language and language order, $F(1,30) = 0.647$, $p = .428$.

3.1.1 English/German AUT and English LexTALE Correlation Results

A correlation analysis in RStudio was performed between the English AUT scores, the German AUT Scores, and the English LexTALE scores to test if the participants' vocabulary knowledge in English was related to their performance on the English and German AUT. Results showed a positive, and significant, correlation between vocabulary knowledge in L2 English and their performance on the AUT in L2 English, $r = .373$, $p = .036$. English LexTALE scores did not significantly correlate with performance on the German AUT tasks, $r = .220$, $p = .226$.

I also analyzed whether participants' performance on the AUT task in their L1 was related to their performance in their L2. Results showed a positive, and significant, correlation between participants' performance on the AUT in their L1 and L2, $r = .511$, $p = .003$.

To conclude, the results from the ANOVA show that performance on the German AUT was slightly better than on the English AUT, but this marginally significant difference was not further qualified by the order in which the AUTs were performed. The correlation analysis showed that participants' vocabulary knowledge in their L2 correlated with their performance on the English, but not on the German, AUT.

3.2 Alternative Uses Task: Fluency Scores

Fluency scores were assigned to each participant based on how many alternative uses they came up with in total during their German and English AUT tasks. The average fluency for each participant's performance in their L1 and L2 AUT task were calculated separately by dividing the total number of ideas each participant came up with by the number of objects presented. These averages (two per participant – one from the German AUT and one from the English AUT) were then put into an excel sheet and used in the ANOVA analysis.

To test for differences in fluency performance in L1 German and L2 English, and whether language order had an impact on their fluency scores (the German AUT task first or the English AUT task first), I conducted an ANOVA, with a within-subject variable of Language (English L2, German L1) and a between-subject variable of Language Order (German First, English First). The average scores (and SDs) are presented in Table 8.

Table 8: Mean Fluency Scores (and Standard Deviations, SDs) on the German and English AUTs, for each of the two Language Order Conditions

Language Order	Language Name	Mean (# of ideas)	SD (# of ideas)
English First	German Fluency	7.898	3.786
English First	English Fluency	6.917	2.127
German First	German Fluency	7.898	2.623
German First	English Fluency	6.945	2.313

The ANOVA on participants' fluency scores revealed a significant main effect of language, $F(1,30) = 7.735$, $p = .009$, but no significant main effect of language order, $F(1,30) < 0.001$, $p = .988$. As can be seen in Table 8, participants' AUT fluency scores were higher for L1 German than for L2 English. There was, however, no significant interaction between language order and language, $F(1,30) = 0.002$, $p = .968$.

We also analyzed whether participants' fluency scores from the AUT task in their L1 was related to their fluency scores from the AUT in their L2. Results showed a positive, and significant, correlation between participants' performance in AUT Fluency scores in their L1 and L2, $r = .807$, $p < .001$..

3.3 Remote Associates Task

The Remote Associates Task was scored based on accuracy, since there was only one correct answer for each set of three words presented to the participants. Each participant was given one point for a correct answer and zero points for an incorrect answer. Separately for the German and for the English RAT tasks, the amount of points each participant received were

summed up and divided by the 30, the total number of items in the test, to generate a proportion of correct answers for each participant out of one (100%).

To test for differences in RAT performance in L1 German and L2 English, and whether language order impacted this performance (German RAT task first or English RAT task first), I conducted an ANOVA, with a within-subject variable of Language (English L2, and German L1) and a between-subject variable of Language Order (German First, English First). These average scores (and SDs) are presented in Table 9.

Table 9: Mean Proportion Correct Scores (and Standard Deviations, SDs) on the German and English RATs for each of the two Language Order Conditions

Language Order	Language	Mean	SD
English First	German RAT	0.481	0.247
English First	English RAT	0.162	0.184
German First	German RAT	0.587	0.194
German First	English RAT	0.290	0.176

The ANOVA results revealed a significant main effect of language, $F(1,30) = 107.121$, $p < .001$, and a marginally significant main effect of language order, $F(1,30) = 3.228$, $p = .082$. As shown in Table 9, participants performed better on the RAT task in t heir L1 German than in their L2 English. There was, however, no significant interaction between language and language order, $F(1,30) = 0.125$, $p = .726$.

3.3.1 English/German RAT and English LexTALE Correlation Results

A correlation analysis in RStudio was performed between the English RAT scores, the German RAT scores, and the English LexTALE scores to determine if the participants' vocabulary knowledge in English was related to their performance on the English and German RAT. Results showed a positive, and significant, correlation between vocabulary knowledge in their L2 and their performance on the RAT in their L2, $r = .652$, $p < .001$. English LexTALE scores, however, did not significantly correlate with performance on the German RAT tasks, $r = .224$, $p = .218$. There was also a positive, and significant, correlation between participants' performance on the RAT in their L1 and L2, $r = .691$, $p < .001$.

To conclude, the results from the ANOVA show that performance on the German RAT was much better than on the English RAT, and this significant difference was not further qualified by the order in which the RATs were performed. The correlation analysis showed that participants' vocabulary knowledge in L2 correlated with their performance on the English, but not on the German, RAT.

Chapter 4: General Discussion

This thesis sought to explore German-English bilinguals' convergent and divergent thinking skills in their L2, English, relative to their L1, German, by using the Remote Associates Task for testing convergent thinking abilities, and the Alternate Uses Task for testing divergent thinking abilities. All participants were young adults majoring in engineering. I hypothesized that there would not be a significant difference between the participants' divergent thinking abilities in their L1 vs. their L2, since the AUT divergent thinking task is open ended and the participant can therefore get around lacking a specific L2 word they intended to use by using another word with a similar meaning to get their point across. I also hypothesized that there would be a significant difference between participants' convergent thinking abilities in their L1 vs. their L2 because the RAT convergent thinking task is very dependent on the participants' vocabulary knowledge, since each of the problems corresponded to one specific vocabulary word that counted as the correct answer. The results of this study largely confirmed these hypotheses, as language proved to have a marginally significant impact on divergent thinking outcomes and a significant impact on convergent thinking outcomes.

The other goal for this thesis was to investigate how convergent and divergent thinking skills may be affected by prior, small-group and interactive, problem-solving in participants' L2 English. This was tested by having participants complete a real-world engineering problem in their L2, English, prior to completing either the AUT or RAT. I hypothesized that if the participants performed either of these tasks (AUT or RAT) in their L2 immediately after completing the engineering problem in their L2, they would perform better on that specific task than participants who did not complete the AUT or RAT in their L2 immediately after solving this engineering problem in their L2. The results of this study, however, disproved this

hypothesis, as there was no significant interaction between language and language order for both the AUT divergent thinking task and the RAT convergent thinking task.

4.1 Implications of Divergent (AUT) and Convergent (RAT) Thinking Task Analyses

The results from the AUT creativity analysis indicated that language had a marginally significant impact on the participants' divergent thinking abilities (which was not further qualified by the order in which the AUTs were performed, as language order had no impact on the participants' performance on the AUT). A plausible reason why language did not significantly impact individuals' divergent thinking skills is because of how open-ended and flexible the AUT is, which ultimately creates endless possibilities of creative uses for each of the objects presented. If the participant comes up with a creative idea for the usage of an object but lacks a specific L2 word to describe their idea, they can still get their point across by using another word with a similar meaning in their L2 that they do know. The results from the AUT Verbal Fluency Analysis, on the other hand, revealed that language had a significant impact on the participants' verbal fluency scores, as participants exhibited higher overall fluency scores in German, their L1, as opposed to English, their L2. This makes logical sense, as individuals have more practice and experience using their first/native language and therefore will be able to generate more creative ideas for a given object in their L1 (M = nearly 8 ideas) as opposed to their L2 (M = nearly 7 ideas) within the 3 minutes that they are given to present creative alternative uses.

The results from the RAT convergent thinking analysis indicated that language had a significant impact on the participants' convergent thinking abilities (which was indeed further qualified by the order in which the RATs were performed, as language order had a marginally

significant impact on the participants' performance on the RAT). As predicted, a probable reason for the significant effect of language on convergent thinking abilities is that each of the 30 prompts presented to participants required them to answer using one specific vocabulary word that fit each prompt. If they did not successfully answer using this word, participants received no points for their answer. Therefore, unlike the AUT task, the participants' performance on the RAT task in both their L1 and L2 was strongly dependent on their vocabulary knowledge in both languages respectively.

Correlation results indicated a significant impact of the participants' English vocabulary knowledge on their performance in both the AUT and RAT tasks in their L2 English, but no impact of the participants' English vocabulary knowledge on their performance in either the AUT and RAT task in their L1 German. This pattern implies that participants with a higher vocabulary knowledge in their L2 attain higher scores on the AUT and RAT, again confirming that convergent and divergent thinking outcomes are strongly related to L2 vocabulary knowledge, and more so than L1 vocabulary knowledge. The correlation analysis also indicated a positive and significant correlation between the participants' performance in both the AUT and RAT in their L2 and L1. A plausible reasoning for this finding is that if participants are good at coming up with divergent or convergent thinking outcomes in their L2, they are also more likely to be able to do the same in their L1.

4.2 Explanation of AUT and RAT Results based on Semantic Networks

Overall, research has proven that creative thinking stems from an individual's semantic network abilities (Colins & Loftus, 1975). Borodkin et al. (2016) performed a study where 27 English-Hebrew bilinguals conducted semantic fluency tasks in their L1 English and L2 Hebrew.

Borodkin et al. (2016) analyzed these results with a goal of determining the relationship between bilinguals' semantic network in their L2 and L1. The results of this study suggest that an individuals' L2 semantic network is less well-organized than its L1 equivalent. Specifically, the L2 semantic network is more clustered, less modular, and more densely connected locally. Therefore, it would be expected for divergent thinking to be different in an individual's L1 compared to their L2. The results of my study prove that there is a difference between participants' fluency scores on the AUT in their L1 compared to their L2, however there is no difference in the creativity of ideas generated in their L1 compared to their L2. Thus, it can be concluded that the structure of the semantic network affects the quantity of ideas in participants' L1 vs. their L2 (i.e., their fluency scores on the AUT), but does not affect the quality of ideas in their L1 vs. their L2 (i.e., their originality scores on the AUT).

Additionally, Borodkin et al. (2016) concluded that bilinguals had a lower fluency score in their L2 Hebrew compared to their L1 English, which supports the outcome of my study that participants, overall, had a lower fluency score in their L2 as compared to their L1. Another conclusion that Borodkin et al. (2016) made was that participants with a more proficient lexicon in a certain language generated more correct responses than those with a less proficient lexicon in that language. Since an individual's lexicon refers to their vocabulary knowledge, this conclusion supports the results of my study stating that language does have a significant impact on a participants' performance in the RAT convergent thinking task.

Furthermore, the correlation results from this study are supported by past studies and research. Borodkin et al. (2016) proved that bilinguals with a stronger vocabulary score in a language performed better on all tasks in that language, but their vocabulary knowledge in their L1 had no impact on their performance in their L2 and vice versa. This supports my conclusion

that participants' vocabulary knowledge in their L2 impacts their performance on tasks in their L2, but does not impact performance in their L1. Additionally, an individual's L2 vocabulary knowledge is initially connected to their L1 translation equivalents and therefore their vocabulary knowledge in their L1 (Frenck-Mestre & Price, 1997; Kroll & Stewart, 1994), which further supports the conclusion that there is a correlation between participants' performance on all tasks in their L1 and L2.

4.3 Effect of Prior Problem-Solving Activities on Convergent and Divergent Thinking

Correlation results indicated that there was no significant interaction between language and language order on the participants' creativity scores, fluency scores, or their convergent thinking scores. These results prove that there was no effect of embedding bilinguals in their L2 English before starting either the divergent or convergent thinking tasks in their L2. The definitive reasoning behind this conclusion is unknown (as this is based on a null effect), however it can be speculated that participants were not immersed long enough in their second language for the problem-solving task to have any impact on their performance on either task in their L2. This speculation, however, deserves to be further investigated in future studies, as there is no definitive proof that longer immersion in the L2 will impact performance on creative thinking.

4.4 Practical Implications of the Current Study

As previously stated, most engineering educational programs tend to emphasize convergent thinking skills rather than focusing on divergent thinking skills (e.g., Stouffer, Russel, & Olivia, 2004). Recently, a lot of top employers, such as Deloitte in this case, have

noticed that graduating engineers lack important design skills in, for example, problem solving, decision-making, and creative generation of improved alternatives (Morrison, DeRocco, Maciejewski, McNelly, Giffi, & Carrick, 2011). A lack of creativity is viewed as problematic in a rapidly changing technology-oriented world, where innovation is essential to survival and success.

Additionally, a lot of German employers have begun to change their working language to English, including Volkswagen, which is one of the major German automobile manufacturers. Therefore, it is crucial for the success of bilingual engineers working in the field to be able to generate ideas in their second language. In terms of divergent thinking, based on the results of my current study, an employee's ability to come up with a creative solution will not be affected by the language in which they think in, as language was proven to have no impact on the originality measure of their ideas. Only their language proficiency scores in their L2 will impact their ability to think divergently in that particular language. Using their L2 in the workplace, however, will hinder their fluency scores, as it was proven that individuals are able to generate somewhat fewer ideas within a given amount of time in their L2 as compared to their L1. Thus, employers should instead either ask employees to come up with just a few creative solutions to a problem if they are generating ideas in their L2, since there will be no difference in the employee's ability to do so in their L2 vs. their L1, or give employees more time to generate ideas. Conversely, language does have a significant impact on individuals' convergent thinking abilities. In this study it was proven that if individuals have to put their mind towards solving a problem that only has one possible solution, like the prompts given in the RAT convergent thinking task, they were more successful at solving this problem in their L1 than they were in

their L2. Therefore, it is more effective for employers to have employees generate solutions to convergent thinking problems in their L1 than in their L2.

APPENDIX

Table 1: List of German and English items used in the AUT

Attribute (English)	Attribute (German)
brick	Der Ziegelstein
button	Der Knopf
car tire	Der Autoreifen
chair	Der Stuhl
fork	Die Gabel
hat	Der Hut
key	Der Schlüssel
knife	Das Messer
microphone	Das Mikrofon
napkin	Die Serviette
newspaper	Die Zeitung
pencil	Der Stift
rope	Das Seil
shoe	Der Schuh
spoon	Der Löffel
toothbrush	Der Zahnbürste

Table 2: Detailed AUT Creativity/Originality Rating Scale

Not creative	Little creative	Quite creative	Very creative
0	**1**	**2**	**3**
Completely uncreative idea	Obvious idea	Good idea	Very good idea
Very common or senseless	Somewhat unusual	Rather original and sensible	Original and sensible
Everyone can think of this	Many people may think of this sooner or later	Not something everyone comes up with	Very few people can think of this

Table 3: List of German items used in the RAT

Attribute 1	Attribute 2	Attribute 3	Solution
Schirm	Finsternis	Blume	Sonne
Wachs	Duft	Ständer	Kerze
Kaffee	Schnabel	Porzellan	Tasse
Teller	Kasper	Gemüse	Suppe
Raps	Plattform	Preis	Oel
Falte	Ausschlag	Kontakt	Haut
Wurm	Wetter	Tonne	Regen
Hals	Fahrrad	Perle	Kette
Minze	Korn	Kuchen	Pfeffer
Welt	Hagel	Billard	Kugel
Schwein	Rettich	Jungfrau	Meer
Programm	Wirus	Kurs	Computer
Reifen	Werkstatt	Bombe	Auto
Keule	Braten	Blümchen	Gans
Tumor	Blutung	Masse	Gehirn
Block	Klinge	Spitze	Messer
Larve	Pilz	Gewicht	Fliege
Bekenntnis	Herpes	Stift	Lippe
Film	Blech	Spray	Dose
Ruhe	Sommer	Kaffee	Pause
Plan	Rundfahrt	Rat	Stadt
Elch	Aids	Pilot	Test
Nacht	Knopf	Kragen	Hemd
Heft	Titel	Internet	Seite
Vogel	Hocker	Wespe	Nest
Joker	Kabel	Nummer	Telefon
Streit	Bruch	Versprechen	Ehe
Spiegel	Qualität	Röhre	Bild
Stirn	Achsel	Mund	Hoehle
Deutung	Note	Tänzer	Traum

Table 4: List of English items used in the RAT

Attribute 1	Attribute 2	Attribute 3	Solution
duck	fold	dollar	bill
fountain	baking	pop	soda
cream	skate	water	ice
political	surprise	line	party
measure	worm	video	tape
preserve	ranger	tropical	forest
cracker	fly	fighter	fire
worm	shelf	end	book
date	alley	fold	blind
nuclear	feud	album	family
loser	throat	spot	sore
sleeping	bean	trash	bag
food	forward	break	fast
sandwich	house	golf	club
show	life	row	boat
print	berry	bird	blue
safety	cushion	point	pin
high	district	house	school / court
cadet	capsule	ship	space
hound	pressure	shot	blood
aid	rubber	wagon	band
sage	paint	hair	brush
french	car	shoe	horn
sense	courtesy	place	common
flower	friend	scout	girl
peach	arm	tar	pit
cottage	swiss	cake	cheese
fox	man	peep	hole
main	sweeper	light	street
pike	coat	signal	turn

Table 5: List of German items used in the LexTALE Task

Combination of Letters Presented	Is it a Real English Word?		Combination of Letters Presented	Is it a Real English Word?
mensible	nonword		plaintively	word
scornful	word		kilp	nonword
stoutly	word		interfate	nonword
ablaze	word		hasty	word
kermshaw	nonword		lengthy	word
moonlit	word		fray	word
lofty	word		crumper	nonword
hurricane	word		upkeep	word
flaw	word		majestic	word
alberation	nonword		magrity	nonword
unkempt	word		nourishment	word
breeding	word		abergy	nonword
festivity	word		proom	nonword
screech	word		turmoil	word
savoury	word		carbohydrate	word
plaudate	nonword		scholar	word
shin	word		turtle	word
fluid	word		fellick	nonword
spaunch	nonword		destription	nonword
allied	word		cylinder	word
slain	word		censorship	word
recipient	word		celestial	word
exprate	nonword		rascal	word
eloquence	word		purrage	nonword
cleanliness	word		pulsh	nonword
dispatch	word		muddy	word
rebondicate	nonword		quirty	nonword
ingenious	word		pudour	nonword
bewitch	word		listless	word
skave	nonword		wrought	word

Table 6: List of English items used in the LexTALE Task

Combination of Letters Presented	Is it a Real German Word?	Combination of Letters Presented	Is it a Real German Word?
welstbar	nonword	eimerweise	word
reuevoll	word	scheil	nonword
zuoberst	word	stockfest	nonword
ruppig	word	mehlig	word
peturat	nonword	dämmrig	word
klaglos	word	garen	word
zugig	word	trachter	nonword
turbulenz	word	anprobe	word
zehe	word	monströs	word
degeration	nonword	sonität	nonword
untief	word	speicherung	word
züchtung	word	malodie	nonword
pensionat	word	narke	nonword
zapfen	word	strähne	word
staksig	word	destillation	word
stalmen	nonword	leuchte	word
malz	word	flinte	word
feige	word	mackel	nonword
fürren	nonword	entsachtung	nonword
rasend	word	geograph	word
feist	word	summierung	word
klempner	word	waghalsig	word
ausreben	nonword	zierde	word
kannibale	word	faunik	nonword
schwachheit	word	ludal	nonword
erbarmen	word	klamm	word
vermastigen	nonword	draunig	nonword
subversiv	word	flistor	nonword
satteln	word	unstetig	word
plang	nonword	herzig	word

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ACADEMIC VITA

EDUCATION:

The Pennsylvania State University — **University Park, PA**
Schreyer Honors College — *May, 2021*
B.S. Chemical Engineering and German

WORK EXPERIENCE:

- **I had two potential Internship opportunities lined up for the Summer of 2020 at Cray Valley Chemicals and Carlisle Construction, however due to COVID-19, I was unable to complete either of these Internships.**

Cray Valley Chemicals – TOTAL SE — **Chester Springs, PA**
Summer Engineering Intern — *May, 2018- July, 2018*

- Learned and safely operated 11 different pieces of equipment such as the Gas Chromatography, Gel Permeation Chromatography, and Differential Scanning Calorimetry Systems to analyze and evaluate if the properties of the specialty chemicals sent by plants nationwide matched the chemical guides created and distributed by Cray Valley Chemicals
- Collected chemical property data from 16 Styrene Maleic Anhydride (SMA) resins and used the results to update outdated chemical guides so that these older and unused resins could be resold for a profit
- Manipulated variables of the Wingtack® 10 product through daily reactions in collaboration with international team members to develop a more bio-sourced version of this current resin additive that would be more marketable in our developing economy and could be sold to 3 consumers who had requested this change

RESEARCH:

Chemical and Biological Systems Optimization Lab — **University Park, PA**
Undergraduate Research Assistant — *May, 2020 – August, 2020*

- Researched and collected data from databases such as BiGG, PubChem, KEGG, and CHEBI for 2,700 Metabolites to be used in the 2 existing models (CattleCyc and iMyocyte2419) created by graduate students for a cultivated meat production project

Chemical Engineering Research Lab — **University Park, PA**
Undergraduate Research Assistant — *August, 2017 – May, 2018*

- Developed and researched the Autothermal Thermophilic Aerobic Digestion Process (ATAD) in collaboration with a graduate student
- Centrifuged and dried samples in falcon tubes to collect percent solid data that was later analyzed and compared to samples taken from the Pilot Plant using Excel to confirm its accuracy
- Monitored culture plates to assist a fourth-year student in a molecular biology research project involving the manipulation of cyanobacteria to find a more convenient vaccination for the HIV Virus

INTERNATIONAL EXPERIENCE:

Technical Institute of Brunswick — **Brunswick, Germany**
Independent Research Scholar — *May, 2019- July, 2019*

- Pursued an independent research project investigating the convergent and divergent thinking of bilingual Engineering Majors in their first and second language with a goal of conducting analyses and crafting a paper to aid studies being pursued in the Penn State Linguistics and Psychology Laboratory
- Designed, developed and programmed cognitive thinking tasks using E-Prime and E-Studio to test 40 personally recruited German Engineers

LEADERSHIP AND INVOLVEMENT:

Penn State Dance Marathon (THON) — **University Park, PA**
Head Chair — *April, 2020 – Current*

- Plan, lead, and oversee all fundraising events held by our organization to raise money for the world's largest student run philanthropy
- Spearhead efforts to establish a new organizational structure that will help maximize our fundraising efforts and involvement
- Battled the COVID Rules & Regulations to creatively find new and alter past fundraising efforts help by our organization that comply with these rules
- As Head Family Relations Chair for THON 2020, raised $141,000 | As Head Overall Chair for THON 2021, raised $180,000 & ranked 3rd in terms of Greek Organizations, the most we've ever raised and highest ranking we have ever received

South Proper Housing — **University Park, PA**
Sorority Assistant — *April, 2019 – May, 2020*

- Served as a liaison between the Sorority Chapter and Residence Life, Housing, Assignments, and Fraternity and Sorority Life
- Collaborated with Resident Assistants in the community to manage issues, questions, and concerns of the 34 sorority members living in the residence halls and provided resources for the residents when necessary
- Collaborated with the University to create and manage the floor roster, room assignments, and room changes for multiple semesters

Kappa Alpha Theta Sorority — **University Park, PA**
Scholarship Director — *January, 2019 – January, 2020*

- Worked alongside the Alumni Scholarship Director in finding ways to aid struggling members academically, such as one-on-one meetings, weekly study sessions, and mentorship programs
- Researched and reported awards and scholarships to the Chapter on a weekly basis for those who exceeded academically

AWARDS, SKILLS AND CERTIFICATIONS:

Awards and Certifications: $10,000 Federal Grant from the Partners of International Research and Education (PIRE), $2400 Scholarship from South Proper Housing, Outstanding Junior Award for Kappa Alpha Theta, Freshman Award for Academic Excellence

Skills: Proficient in use of Mathematica, Aspen Plus, MATLAB Programs, and Microsoft Office Suite; Skills in Project Management, Collaboration, Research, Problem Solving, Organization, Leadership; Interpersonal Skills & Safety-Oriented Mindset