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Framing in Biology: Conception and Interpretation of Arrows

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by

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The Thesis of Han-Yue-Emerald Liu is approved, and it is acceptable in quality and form for publication on microfilm and electronically:

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ABSTRACT OF THE THESIS

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Master of Science in Biology

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Biology frequently describes many abstract phenomena such as, but not limited to, DNA replication in the cell growth cycle, proton transportation in the energy production process, and ligand activation in the immune response system. Instructors often communicate such complex phenomena through symbolic representation. Students' performance on exams and research papers limitedly gauge their understanding of the concepts. For example, it is uncommon for instructors to have time or opportunity to examine how well students understand some of the essential aspects of biology representations. Since the student population in the university system is becoming more diverse, we wanted to examine the relationship between English familiarity and interpreting one of the most common symbols used in biology textbooks, arrows. Through surveying 1969 students in multiple introductory biology courses, we evaluate the preciseness and consistency of students' understanding of various types of arrows in the biological context. In our findings, English proficiency is correlated with students' decisions when decoding the meaning of an arrow. In our exploratory research on the possible relationship between the visual representation and written description of arrows in biology, there exists enormous variation in understanding the meaning of arrows among all students, regardless of language status. We suggest the instructors in the biological field restate and enforce the specific and consistent usage of symbols.

Introduction

Biology is a tricky subject because natural phenomena are complex, abstract, and unfamiliar throughout daily life (Bennett 2005; Brown and Schwartz 2009; Rotbain, Marbach-Ad, and Stavy 2008; Schmid and Telaro 1990; Sesli and Kara 2012). Biological events are like all other occurring phenomena, complex, random, often abstract with complicated patterns intertwined with each other. Biology, however, is the systematic sorting of the events that mean to rationalize the connection, pass down the knowledge, and point out the unsolved to others. The receiver of the information uses it to make sense of the biological event, to make further discoveries, and to fill in the gap of understanding. The famous apocryphal apple dropped on Sir Newton's head that led to the development of the gravity concept is a random event. The creation of the gravity equation to explain the falling apple is scientific progress. Monk Mendel discovered the genetic component concerning observable traits in peas that ultimately created the Punnett Square for prediction. The most significant difference between biological events and Biology is the preciosity. When the information is delivered, the message has to be lucid, focused, and logical.

Nonetheless, logic is biased under the context of language-and-thought relation, which language may influence thoughts, and language diversity is crucial for cognitive activities (Zlatev and Blomberg 2015). Languages have core differences in every level of the description, sound, grammar, lexicon, and meaning. There are multiple investigations on the influences of language to human cognitive activities, such as color perception (Thierry et al. 2009), odor sensation (Majid and Burenhult 2014), spatial cognition (Gentner et al. 2013), conception of time (Fuhrman et al. 2011), mental arithmetic (Ellis 1992), even moral judgment (Hayakawa et al. 2017). Numerous neuroimaging studies showed a language-dependent exact calculation network (Dehaene et al., 1999; Cohen et al., 2000; Gruber et a., 2001; Stanescu-Cosson et al., 2000). Multiplication is lying relatively more on arithmetic facts that can be extracted from memory. Subtraction heavily depends on the mental manipulation of quantities. However, addition utilizes both solving processes (Dehaene et al., 2004). Later investigation illustrated a higher error percentage in sophisticated addition when instructed in the second language despite the high proficiency in both the first language and second language (Van Rinsveld et al. 2017). The fMRI brain scans may implicate the less efficiency of the brain network using the second language. Since science education is a process of cognitive change (Carey 2000; Keil 1992) and the effect of language steering the cognitive development, divergent understanding in a student might be observed. Interestingly, multilingualism may have an advantage in learning science. When one is fluent in multi-linguistic logic that able to convert in-between them freely, they can solve different tasks accordingly (Kearsey and Turner 1999). However, if the students cannot adaptively utilize both thinking patterns of language, it exhibits a significant disadvantage for learning (Kearsey and Turner 1999).

With globalization and a growing number of higher education students from non-dominant linguistic backgrounds ("The Condition of Education - Preprimary, Elementary, And Secondary Education - Elementary and Secondary Enrollment - English Language Learners In Public Schools - Indicator May (2019)" 2019), science for all has become more challenging. Science instruction involves more than speaking, listening, reading, and writing; it has the nature of observation, prediction, analysis, summary, and presentation with graphs, tables, drawing, writing, and speech (Lee and Fradd 1998). The recent research of Arrows in Biology showed the lack of clarity and consistency of the abstract representation of fundamental biology concepts (Wright et al. 2018). In our exploratory study, we intended to understand the inconsistency in the understanding of the biological image of arrows. There is a humongous variation of selections of the arrow's meaning and representation of biological concepts among students evident from Wright's research. To expand on it, we have evaluated the association of the meaning of arrows with biological concepts in different English proficient groups through survey collecting. We hypothesized that students' state of English proficiency influences their cognitive understanding of representations of biological concepts.

Theoretical Framework

In our study, the lens of the principle of linguistic relativity was used to qualify and quantify the relationship between English proficiency and interpretation of Biological representation and concept. As for the connection between the variation of interpretation and the language background, we employ the linguistic mediation theory. The Sociocultural Theory of Vygotsky stemmed from constructivism (Piaget 1976), views "development as co-constructed" (Cole and Cole 2001), guided the notion of linguistic mediation of cognitive development. Language is a cultural artifact positions as a psychological tool that mediates the exchange between communicators. The communication back and forth between the learners and instructors is the interaction that facilitates the Cultural-historical activity theory (CHAT). CHAT is Vygotsky's cognitive development model, which states the interaction of learners with instructors is mediated by culture artifacts such as language, beliefs, and technology (Vygotskiĭ 1930; 1962; Vygotskiĭ and Cole 1981; Vygotskiĭ and Kozulin 1986). The interaction through artifact mediation is the essence of learners' psychological development.

Conceptual Framework

We build on the Principle of Linguistic Relativity and Sociocultural Theory. With the fusion of them, we scoped the question through the conceptual framework illustrated in figure 1, which demonstrates the flow of biological information from instructor to student. From top to bottom, we inspect each stage of the utility of education materials in life science. First, the instructors, as a professional community, assume to have a uniform cognitive understanding of a biological concept due to their profession and expertise through research. Hence, they can provide a stellar example of a biological concept. For instance, instructors in a four-year university and two-year college understand that concentration gradient is a mechanism of energy. However, every instructor could and most likely would use different analogies to explain the biological concept in terms of an abstract concept according to their background. The construction of examples is bound to the frame of their language navigating the expression of the idea. Therefore, the visual and descriptive representations of the biological concept are encrypted with a linguistic undertone.

With these assumptions, we hold the instructional variables constant when measuring the students' interpretations of biological symbols and reflections of biological concepts. Our experiment zooms into the consideration of students' understanding and weights the language component on learning biology, where students' selection of representation or concept reflects their underpin idea of the given conception. From the representation point forward, students are the solo players on dissecting and digesting the information. There are more than a few "correct" ways take-in the information provided. There are multiple divergent when we consider the existing background knowledge and linguistic framing that the student population possesses. Therefore, we hypothesize a wide distribution of understanding on a single idea.

Method

The use of human subjects' information for this study was reviewed and approved by the Institutional Review Boards of the University of California, San Diego (UCSD), file number 181077XX.

According to UCSD's enrollment demographic, 18.6% (5,628) International Citizen attended, and 18.5% (5,613) declared Biology major in the 2018-2019 academic year (UCSD, Undergraduate Student Profile).

Data Collection

The survey was based on the previous study conducted by Wright.et.al, published in 2018 on CBE-life sciences education (Wright et al. 2018). In the study, the team sought to gain knowledge of the preconceived idea of particular arrows used in biology textbooks. Without alternated the prompts of any questions on the survey, we moved the demographic portion to the end and collected different sets of the background of interest. We included the number of years fluent in English and the number of years of fluent in non-English languages to construct the data analysis among other demographic questions - see full survey in supplementary files.

Moreover, we divided the original survey into two parts. Part-I provided students with a biological conceptual description, and they were asked to select arrows to represent that concept. Part-II provided students with symbolic representations, and they were asked to choose biological concepts they felt were illustrated by the provided images. Wright.et.al showed in their investigation that there are multiple arrows used to represent the same concepts and vice versa. Thus, compared to Wright et al., we altered the responding format to rank the top three selections that deemed as most associated with the prompted arrow (Part-I) or the biological concept (Part-II). For example, instead of a single answer (e.g., multiple-choice format), in our ranking system, the most appropriate choice was selected as the first option (rank-1), the next most representative choice as the second option (rank-2), and the last better-aligned choice as the third option (rank-3) - the full survey attached onto the supplementary files.

The survey was formatted, distributed, and collected through Qualtrics from Summer 2018 through Fall 2018. An email invitation to participate in the study was first sent to the instructors of select lower-division Biology courses, along with the request to award a trivial amount of the course credit upon finishing the survey. Students who did not want to participate in the study could complete an alternative assignment for the bonus course credit. In total, there were 2005 UCSD undergraduate students from nine lower-division biological courses from either lecture or lab who participated in this study. Responses were anonymous.

We also conducted 15 individual interviews with students recruited from the same student population (volunteers were compensated $15 for participating). The interviewee may or may not have participated in the survey. The purpose of the interviews was to get insights about their decision-making process when prompted by the survey questions. In the beginning, the interviewees were given instructions to participate in thinking out loud format while taking the survey in front of a computer. The research team recorded computer screen activities and verbal dialogs. The research team will ask follow-up questions such as “why did you rank the selection this way?” However, we tried to minimax the influences of the researchers. Hence, if the student is giving detailed thought processes, we tend to only listen without intrusion.

Data Analysis

The raw survey data was extracted and organized using MS Excel. We went over the raw data and excluded the 34 individuals that had mismatch inputs in the year of practice in English. For example, subject R_4SZDiTjLGVYXpTT stated as a native English speaker that does not fluently communicate in other languages but indicated less than ten years of fluency in English. Since we rarely encounter ten-year-old college students, the entry was considered at fault. After the removal of erroneous entries, we used MATLAB to analyze 1016 and 955 data points from Part I and II, respectively.

We consolidated the participants by their self-identified fluency of English to question the effect of language fluency in the intrinsic understanding of arrows in a biological context. The rank-3 selection was not taken part in the analyzing process due to general interview responses, such as “I just randomly pick one for the third option” and “None of them fits, but I have to pick one to continue the survey.” We counted up the total number of each type of arrows in rank-1 of the criteria group, then divided by the number of participants in that group and sorted from highest to lowest frequency. Likewise, we gathered the proportion of rank-2 selection.

By using Cross-Tabulation, we split the data into criteria groups (subsample = n) by their English proficiency, and each group’s correspondence for each question. For instance, some students reported that English is their only native language, which implies that they are at least fluent in English since childhood. Such individuals are included in the more than ten-year (≥ 10 years) test group. Some students labeled themselves as multilingual with six-years of English fluency. We consider them in the less than seven-years (< 7 years) and more than five-year (≥ 5 years) test group. Then we determined the probability value (p-value) with a Two-tailed Chi-square Test of Independence with Bonferroni's correction (Curtin and Schulz 1998) and effect-size (V) of Cramer's V with bias correction analysis (Bergsma 2013) for larger than 2-by-2 dimension. The V informs about the strength of the association between 0 to +1, which zero is no relation at all, and one is strongly related. The alpha cutoff of the significant test was set to 0.001 due to the limitation of the statistical analysis, which is highly sensitive to the sample size. In large samples, the scientific finding of significant may be trivial and less relevant to the main question.

Result

We present our findings in this session that examines through the theoretical lenses.

Few Arrows Possess Inherent Meaning

Wright's study used a multiple-choice system that evaluated the perceived meaning of the arrows in the biological context (Wright et al. 2018). During the interview, students expressed the indifference between rank-1 and rank-2, such as, "I think this answer could be either picked first or second, they meant the same to me." Hence, we tally up the frequency of both rank-1 and rank-2 to better represent the comparison of the multiple-choice system with the ranking system. Wright's research found moderate to strong consensus from students about the meaning of these arrows in Table 1 & Table 2. Our results, however, exemplify the mosaic nature of the contextual meaning of the biological arrows, similar to how Wright's data showed the variations in the meaning of arrows used in textbook representations.

In Table1, the previous analysis (Wright et al. 2018) suggested that these three arrow styles presented may have consensus meaning among their sample participants. The arrow shown in Tab.1-I carried the sense of "inhibition of the chemical reaction." However, we found that "negative consequence" was also a frequent choice for the particular arrow. The arrow in Tab.1-II was previously suggested to represent the "concentration gradient" concept. However, our data show that the meaning does not reflect the majority understanding (less than 50% of participants) of the biological meaning embedded in the arrow. The arrow does not have any associated concepts with at least 50% of the selection. At last, the arrow in Tab.1-III seems to be the only one that carries a consistent meaning over half of the participations, and the second-highest choice is less than 50% in both studies.

In comparison to Table 1, where students were shown an arrow and asked to assign meaning to it, Table 2 summarizes some of the results of different question types. Here students were prompted by the students with biological concepts and asked to rank arrows to represent the given idea best. Tab.2-I shows that compared to the previous study, where students identified a particular arrow for “concentration gradient,” significantly fewer students (28.43%) in our population chose that same arrow. Most impressive, Tab.2-II expounds a nearly perfect example of how there can be dual representations of a single concept, in this case, “light emitted.” The most frequently chosen arrow identified as the “best match” (rank 1) also selected as the second most frequent of the next best match (rank 2) and vice versa - the most frequently chosen arrow identified as the next best match (rank 2) was the second most commonly accepted arrow for the “best match” (rank 1). Compared to Wright’s analysis, our data encapsulated the indifference between the selectivity of the representations of the concept “light emitted.” Our ranking data drill out more variance of respondents from undergraduate students than using the multiple-choice method.

English Proficiency, a Language Factor

In the previous sessions, we saw many variations of understanding in students (cit.). To identify if English proficiency variation influences the knowledge of arrow representations, we compared student arrow choices depending on their self-reported proficiency in Figure 2. Three comparisons were made: 1) students with more or less than ten years of English proficiency, 2) students with more or less than seven years of English proficiency, and 3) students with more or less than five years of English proficiency. Students were prompted to select an arrow to represent the biological concept of “concentration gradient.” The blocks of the stack graph exemplify the percentage of corresponding arrows in the sample population. The distributions of ≥ 10 years, ≥ 7 years, and ≥ 5 years appear to be very similar, but < 10 years, < 7 years, and < 5 years, on the other hand, more spread out as the length of year decreases. Thus, English proficiency may correlate with the inconsistency of the concept representation in students.

The seven-year mark separates the most robust relationship between the option distribution and English proficiency with the smallest chance being a random pattern recognition (Fig.2-II). There is also a significant difference in choices when separated by ten years of proficiency (Fig.2-I). However, the effect size suggests the language influence is lessened compared to 7 years. In contrast, the five-year separation mark does not statistically support the association (Fig.2-III), because the p-value accounts for the enormous difference between the subsample sizes. However, the effect size is still adequate, proposing that language dependency at a five-year mark cutoff is still relevant. The distribution of the arrow choices among < 5 years is visually quite different compared to ≥ 5 years. The variations between < 10 years vs. ≥ 10 years and < 7 years vs. ≥ 7 are likely due to the participants in < 5 years group. The presenting data supports the linguistic learning limitation on the overall understanding of a second language that requires five to seven years of practice to reach a similar level of native speakers (Collier 1989). In the following analysis, we split our data into ≥ 5 years as the control group and < 5 years as the comparing group to compare the most appropriate (rank 1) choices. Participants of < 5 years were 42 students, and ≥ 5 years were 973 students if not stated otherwise.

Proficiency of English Correlated with Common (concrete) vs. Scientific (abstract) Concepts

Figure 3 displays the distinction of language factor between the common concept (damage) and scientific concept (external) of force. Fig.3-I shows almost no language proficiency effect between the subgroups when prompted with the question: “This cell is being damaged. Which diagram would you choose to show the injury on the cell?” On the other hand, the question: “This cell is being acted on by an external force. Which diagram would you choose to show the force on the cell?” instantiate significantly and a moderate association between the English proficiency and the correspondent distribution in Fig.3-II.

Comparing Language Effect in Arrow Only vs. Object with Arrow

Figure 4 compares the same biological concept in a different contextual situation. Fig.4-I was prompted by the biological concept of energy/light and given ten arrows to select; Fig.4-II was asking the students to choose from six figures to show light being emitted from the blue object. Students performed noticeably more inconsistent as a group when required to pick an arrow to represent

Energy/light versus having more contextual cue as the legend demonstrated in Fig.4-II. Fig.4-I has a higher significance and magnitude of the English proficiency effect than Fig.4-II. Besides, there was a more substantial influence of English proficiency when asked to select an arrow drawn in Fig.4-I, suggesting that more information in the representation decreases the weight of the language effect in this case.

Proficiency of English Correlated with Academically Familiar vs. Unfamiliar Scientific Concepts

The similar distinction of proficiency effect also appears in between the academically familiar and unfamiliar biological concepts in undergraduate students. The “positive consequence” discussed more often than “negative consequence” in the survey institute, observed by course materials. Hence, one concept is more familiar to students than the other. The concept of “positive consequence” has a small magnitude of the effect of language proficiency on arrow choices in Fig.5-I, but moderate for “negative consequence” despite the insignificant p-value according to our cutoff (alpha) in Fig.5-II. Furthermore, the responses of “negative consequences” are more scattered than “positive consequences” regardless of the subsample division. Notably, ≥ 5 years group has evenly spaced out a distribution that all ten choices have a similar amount of student response.

Biological Diagram Interpretation

Diagrams are one of the key elements in learning biology, and language proficiency also plays a role in deciphering the message. Figure 6 presents the layout that was shown to students, and the response distributions to the questions about this diagram are shown in Figure 7. The questions were: “If you were to encounter this diagram in a biology textbook, what would you think the arrow between A and B is describing?”; “In this same diagram, what is the arrow between A and C describing?” Participants of < 5 years were 37 students, and ≥ 5 years were 917 students. Notwithstanding the differences in arrow meanings are not significant between the students with more or less than five years of English proficiency ($p > 0.0001$), the effect size conveys a moderate association between English proficiency at the five-year marks. In the interview, students expressed the interdependence of interpreting the arrows, such as “If the solid arrow is a certain outcome, then dash one means uncertain, or the other way around.” The contextual relationship between the arrows was also reflected in the survey responses. In Figure 8, for illustration, “chemical reaction” and “certain outcome” were more preferred in explaining the role of the straight solid arrow; on the contrary, the straight dash arrow may seem to reflect the concept of “uncertain outcome.”

Discussion

The purpose of this exploration is to try to pull a thread out of bundle up loose yarns since there has little to none covenant on meanings of biological arrows among beginning biology learners – undergraduate. Our hypothesis tested with a specific group, undergraduate biology students at a single institution that consider the influence factors on students’ educational and demographic backgrounds. The study fleshed out these inquiries:

1. In general, students exhibit wide ranges of interpretations of arrows used in biological representations, in either singular format or diagram construction. Throughout our study, we encounter a wide range of interpretation of arrows, or concepts represented by arrows, as represented by a varied selection of response options in the survey. Selection may reflect students’ understanding of the concepts. The distribution of the collection indicates the inconsistency of understanding in the biological science undergraduate student population as a whole (Table 1 & 2).

2. When students’ self-identified English proficiency was less or equal to five years, there was a notable difference in interpretation when compared with students that are fluent for more than five years (Figure 2). Cummins’s investigation discovered that to perform in academics like the majority of the English natives, non-English native students need about five to seven years of effective English education (Cummins 1981).

3. Concepts that are familiar in daily life across multiple cultures (or languages) are subject to negligible language effects, while abstract scientific concepts suffer from a higher degree of interpretation (Figure 3). Abstract concepts are challenging to form mental models with because we cannot understand what we do not know. If everyday language is used to describe new concepts, students learn the idea better (Brown and Ryoo 2008), because we can position our thinking on other experiences such as cultural context, academic profession and group expertise (Vygotskiĭ 1930; 1962). Fig.3-I shows two popular representations (red arrow and lightning arrow) of “damaged cell” could imply that the interpretation was depending on cultural factors.

4. Descriptions with more contextual cues may decrease the strength of language proficiency effects (Figure 4). This finding could mean that more contextual cues the concept became less

abstract. In the interview, few students indicated the superficial observation of the arrow was their basis of reasoning. For arrow pointing away from the blue object, some said: “The dashed arrow looks like a sunray,” “the straight-arrow looks like a beam of light from a flashlight.” For the arrow only question, some said: “The white color means light/energy.” Students orient themselves more on linguistic cues when having less context rather than the meaning of the construction of the representation.

5. Educational familiar concepts are influenced less by the language effect compared to unfamiliar concepts (Figure 5). When we regularly discuss an abstract concept, it will solidify into a well-framed mental model. It is because we gave them the chance to make connections with well-known examples. Here then, the unfamiliar concept remains flowing unless we ground it with examples, discourse, and experiments (Fredriksen, J. R., and White, B. Y. (1992).). When students do not have the scientific reasoning of a particular concept, they might rely on other logical approaches that help them to make sense of the idea. Fig.5-II illustrates the unexpected pattern that the various arrows were chosen in a similar frequency in the English proficient group (≥ 5 years). Students might use knowledge other than linguistic patterns to try to articulate the “negative consequence.”

6. Linguistic framing can act as an anchor point when interpreting representations that influence future reasoning (Figure 6). The first arrow choice has to be based on understanding, which is shaped by the student’s experience, whether it is scientific or cultural. Students who do not possess the biological reasoning of a concept will try to situate themselves with other factors, languages in this case. Once students committed to a “pseudo” logical flow that seems to be useful for solving problems (arrow from A to B), they tend to follow the pattern rather than relying on language to interpret the meaning. Hence, there is less variation in interpretation as a result of language (arrow from A to C).

Analysis of the results of this study through the lens of linguistic relativity suggests that language has a mediating effect on naive biological learners when it comes to the cognitive processing of the abstract concepts that are not extensively discussed in biology educational situations and daily situations. Under the principle of linguistic relativity, we define the difference between languages are on the surface as different pronunciation or grammatical structure. However, different languages assert unique reasoning frameworks on to the users, influencing the pattern of thinking (Athanasopoulos et al. 2015).

Multilingualism may exist in two categories in cognitive development: first, the ones who use different linguistic framework for different tasks with the capacity of fluent conversion between the framing; second, the ones who are not fluent in the conversion, thus confused by the approach of concepts in between the language framework (Athanasopoulos et al. 2015). People that mentally visualize in all of their languages about the concepts and translate the concepts in between all of the languages are belonging to type one; it means regardless of instruction language; the person will obtain a similar understanding. Type two, however, has a distinct understanding between instructions in their primary language and secondary language(s); type two students have lower performance in problem-solving mathematics but not computations (Macnamara 1967; Collier 1989). The < 5 groups are different from ≥ 5 groups based on the conversion deficit, which the incapability of framing the concept in the instructional language. To illustrate, a student could not position the concept in the framework that the instructor staged and may subconsciously try to investigate the connection in another language framing. The students who can relocate the instructional language in other non-instructional language framing are most likely belong to the ≥ 5 groups. If students that are proficient in English for greater than five years can more fluidly convert between frameworks of thinking, they are more likely to have a convergent way of thinking about concepts or interpreting arrows in biological context (perhaps converging on the most "common" way the representation has been used) — thus resulting in less variations in interpretation compared to students who cannot as easily move between frameworks (less than five years proficient).

Limitation of the Experiment

Nevertheless, our study has areas of improvement that need to be addressed. First, the survey itself embedded language ambiguity in the demographic session where students could misunderstand the range of English fluency in the unit of years. The wording of options was labeled as "more than five years," "more than seven years," and "more than ten years." It seemed as self-explanatory at first, but during interviews, several participants questioned the specification of the categories. Instead, we should have labeled it as "more than five years but less than seven years," and so on. Secondly, the progression of the survey was designated to skip other language inputs for people that claimed to be monolingual in English. However, we should collect their language input as reference checkpoints regardless.

Secondly, students had other culture frameworks that influence their navigation through the tangled web of learning biology. The variation in interpretation or choices observed among the whole surveyed sample suggests that other elements are mediating the stratification of the biological learners' cognitive development. We were not able to isolate these factors from our measurements. In an ideal, fully controlled model, we should expect the control group to be unified, and the experiment group is segregated.

Moreover, when conducting statistical analysis, we did not obtain a similar size of subsamples in criteria groups. Hence, the power of statistical comparison was hindered. However, we adjusted the alpha value to aim to revert the problem. Moreover, the p-value was best calculated by fisher's exact test rather than the chi-square test due to a few close to zero selections (Kim 2017). Due to the complication of fisher's exact in more massive than a two-by-two contingency table, we execute the analysis via chi-square. These constraints might lower the power of statistical analysis.

Nevertheless, we could randomly select the same number of subjects from the ≥ 5 years group to screen with the < 5 years group. Although we would be at risk of losing a lot of the data, the significance should still be noticeable. In the follow-up experiments, we could increase the pool of < 5 years group for comparison.

At last, we would conduct more interviews for two reasons, gain more identification of the possible reasons for variation in student interpretation and ask students to express their mental struggles when language competency might play a role in their interpretations, and whether the language competency impacted their absorption of the biological concepts.

Implication

The confusion soils the misconception in students depending on the level of fluency in the instructional linguistic framework. Figure 8 depicts the model of CHAT of students when mediated by English framing with or without the influence of their non-English native linguistic framework (Davydov 1995). In theory, the students who effectively rationalize the biological concepts within the linguistic framework of American English would optimize their gain of knowledge (green dot). The learners (black dot), however, would most likely fall behind if they are the second type of the multilinguistic user that has conversion deficits (the dot).

According to the revised Bloom's Taxonomy, understand means to "determine the meaning of instructional messages, including oral, written, and graphic communication," in the order of interpreting, exemplifying, classifying, summarizing, inferring, comparing, and explaining (Krathwohl 2002). For students to absorb the information correctly, there should be only a "correct," unambiguous interpretation for a fundamental concept because diverse thinking is useful only when it is built on the correct foundation. In terms of thinking in frameworks, concepts are almost always in relativities. For example, the concept of "big" is not absolute; elephants are big next to humans but not so compared to Earth. In Biology, we often get stuck in absolute frames. For instance, concentration gradient means particles do not spread evenly across the physical space, and they will move from higher density to lower density; however, space is a constraint that allows the concept to be valid in relativity frame.

Our investigation was based on the inconsistency of interpretation of arrows (Wright et al. 2018), which an extension from Central Dogma misconception study from (Wright, Fisk, and Newman 2014). McDermott's study has shown the interference of conceptual misunderstandings with learning new materials (McDermott 1991), most worrisome when the misunderstanding can be rationalized and applied to problems-solving at the moment (Fay and Mayer 1987). A mount of investigation dedicated to identifying misconceptions in biology (Danielson and Tanner 2015; Kinchin 2000; Liu and Lee 2013; Martin, Mintzes, and Clavijo 2000; Pugh, Koskey, and Linnenbrink-Garcia 2014), and many exploring the misconception corrections (Duit and Treagust 2003; Kubisch and Heyne 2016; Lucero and Petrosino 2017). Some studies that show scientific education requires a substantial demand for linguistic competence (Echevarria et al. 2011; Bunch 2013; Lee 2005). Rollnick and Rutherford used the conceptual change model and mixed language strategy to alternating misconceptions on air pressure, which found that mixed language guidance led to a higher percentage of misunderstanding correction (Rollnick and Rutherford 1993). We, hence, infer that misconceptions for some students may result from the conversion deficit of linguistic frameworks that depicted in figure 8 (black and red part of the arrow below the hypotenuse).

Further Action

We might be able to approach misconception with another direction if framework conversion fluency underpinning the cognitive development of learning biology. We should continue to use mixed-methods research (MMR) to investigate the linguistic framing effect on biology misconceptions (Warfa 2016). From the interviews, we gain valuable information about students pursuing the concepts and their interpretations. We could build on the current study and interview with free responses to verify whether the language effect found still relevant in a more open condition. Thus, we could assess students' performance on short answer questions against their proficiency in framework conversion.

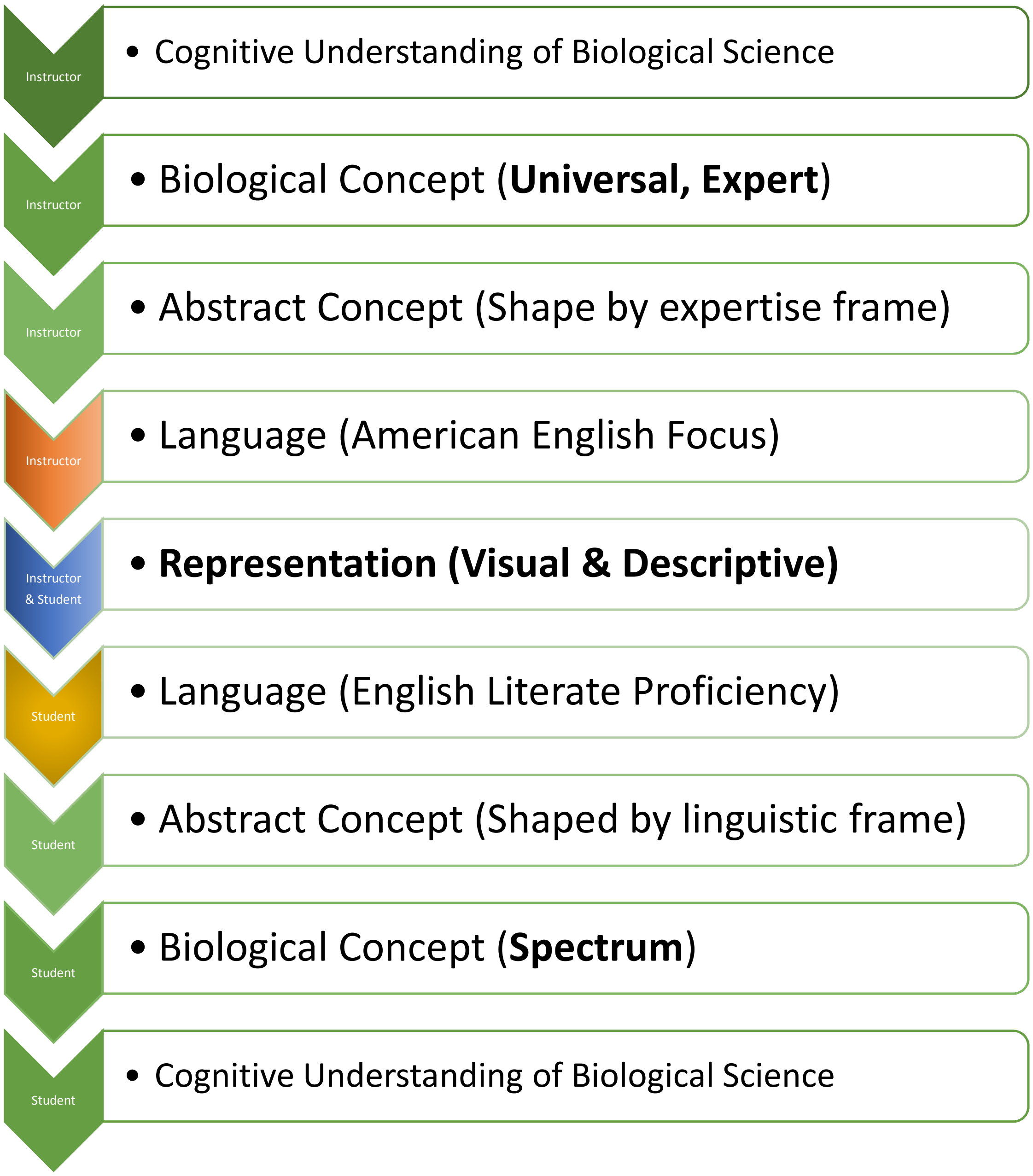


Figure 1. Pathway of knowledge from instructor to student. The information understood by the instructor needed to organize in the universal biological concept that may or may not enclosed by the abstract concept, i.e., time and space. Then, delivery in the linguistical pattern in American English to explain or present the visual and descriptive illustration.

Table 1. Percentage of concepts selected by students. n_a is the amount of participants in our analysis, n_b is the number of participants in Wright's study.

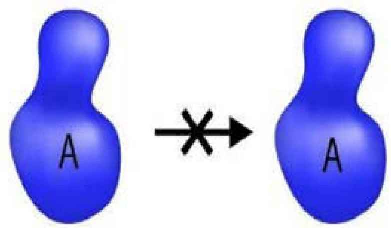
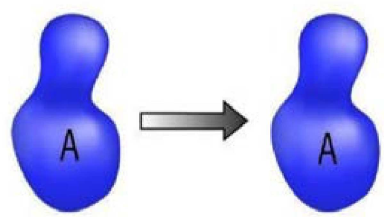
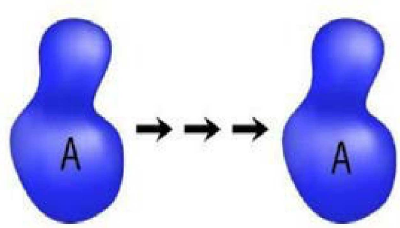
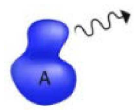
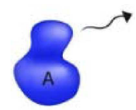
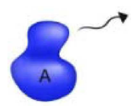
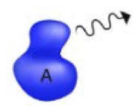
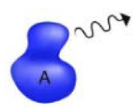
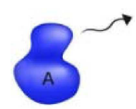
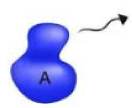
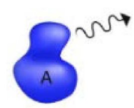
Arrow Diagram Prompt n_a **= 954**		**First highest choice**	**Second highest choice**
	Wright n_b = 189	Inhibition of a chemical rxn **65.00%**	Uncertain outcome 16.93%
	Rank 1 and Rank 2	Negative consequence **61.43%**	Inhibition of a chemical rxn **57.86%**
	Rank 1	Inhibition of a chemical rxn 49.58%	Negative consequence 20.55%
(II)	Rank 2	Negative consequence 40.88%	Uncertain outcome 22.12%
	Wright n_b = 173	Concentration gradient **58.96%**	Time passing 8.09%
	Rank 1 and Rank 2	Concentration gradient 42.14%	Energy or light 25.89%
	Rank 1	Concentration gradient 32.70%	Time passing 15.62%
(III)	Rank 2	Energy or light 18.55%	Chemical reaction 10.59%
	Wright n_b = 169	Multiple steps **72.78%**	Movement in a particular direction 10.06%
	Rank 1 and Rank 2	Multiple steps **66.14%**	Movement in a particular direction 29.87%
	Rank 1	Multiple steps **52.83%**	Time passing 16.56%
(IV)	Rank 2	Movement in a particular direction 18.97%	Multiple steps 13.31%

Table 2. Percentage of arrows selected by students. n_a is the amount of participants in our analysis, n_b is the number of participants in Wright's study.

Biological Concept **n_b = 1015**		**First highest choice**	**Second highest choice**
Concentration gradient (I)	Wright n_b = 142	 **83.80%**	 10.56%
	Rank 1 and Rank 2	 **55.37%**	 43.94%
	Rank 1	 46.50%	 11.92%
	Rank 2	 33.79%	 13.20%
Light emitted (II)	Wright n_b = 142	 **78.10%**	 11.27%
	Rank 1 and Rank 2	 **60.39%**	 **57.83%**
	Rank 1	 38.23%	 20.99%
	Rank 2	 39.41%	 19.61%

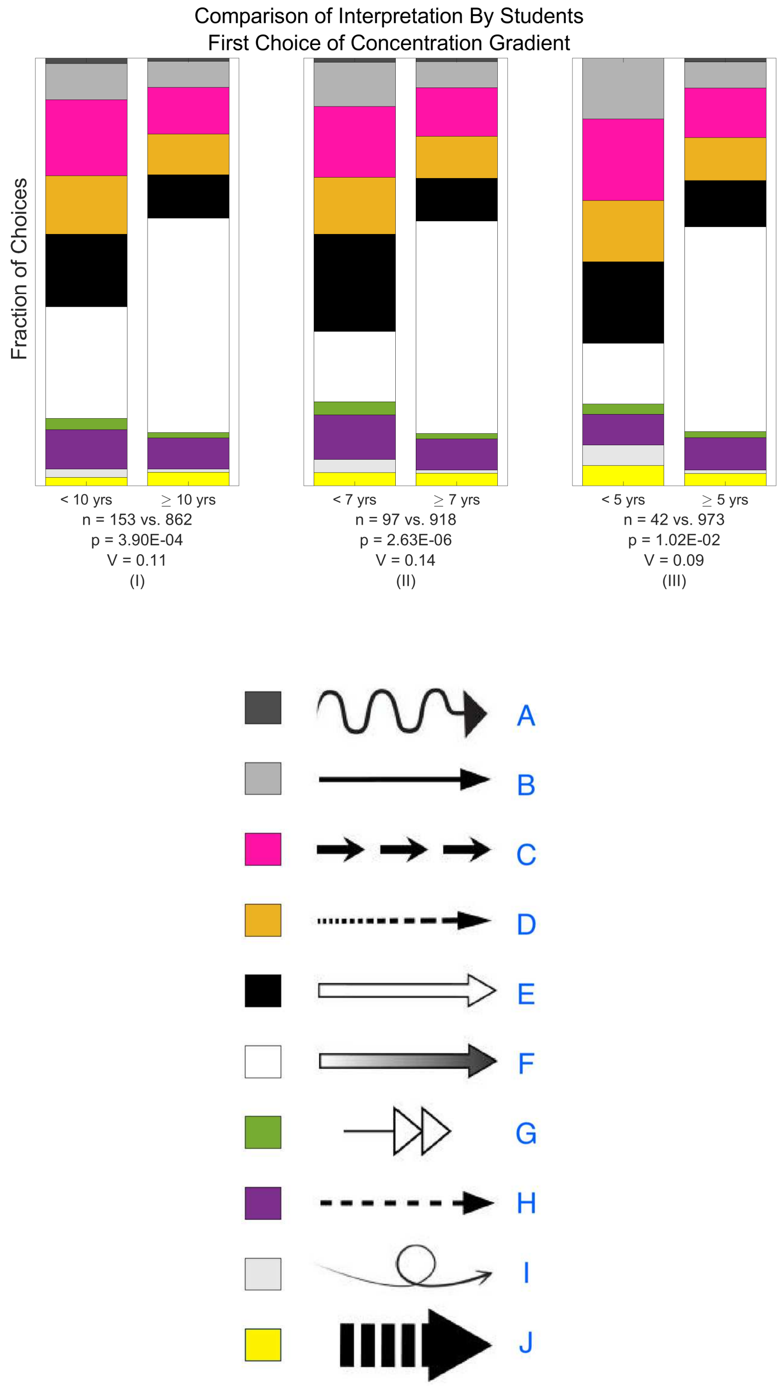


Figure 2. Distribution of selection by three different English fluency criteria.

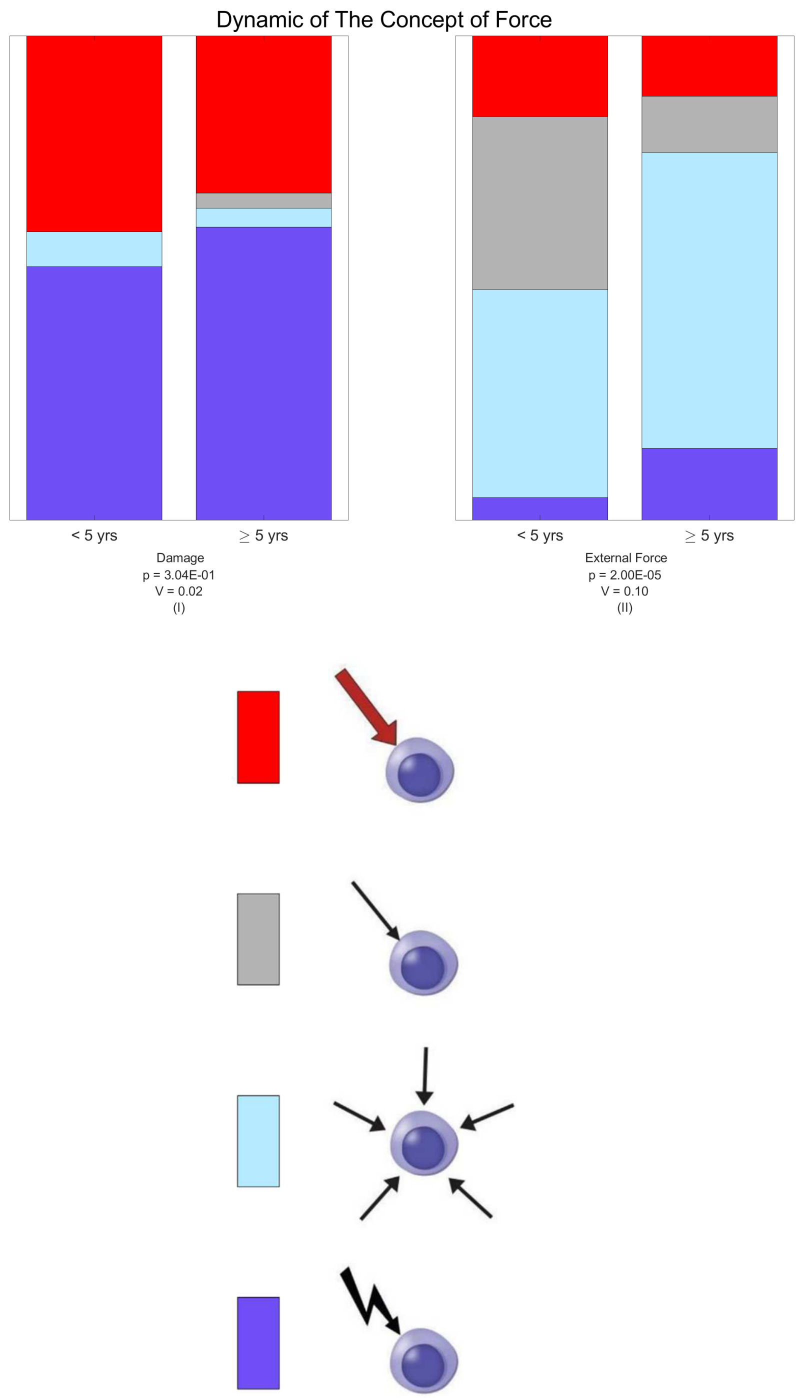


Figure 3. Compare common vs. abstract concepts in relation to language effect.

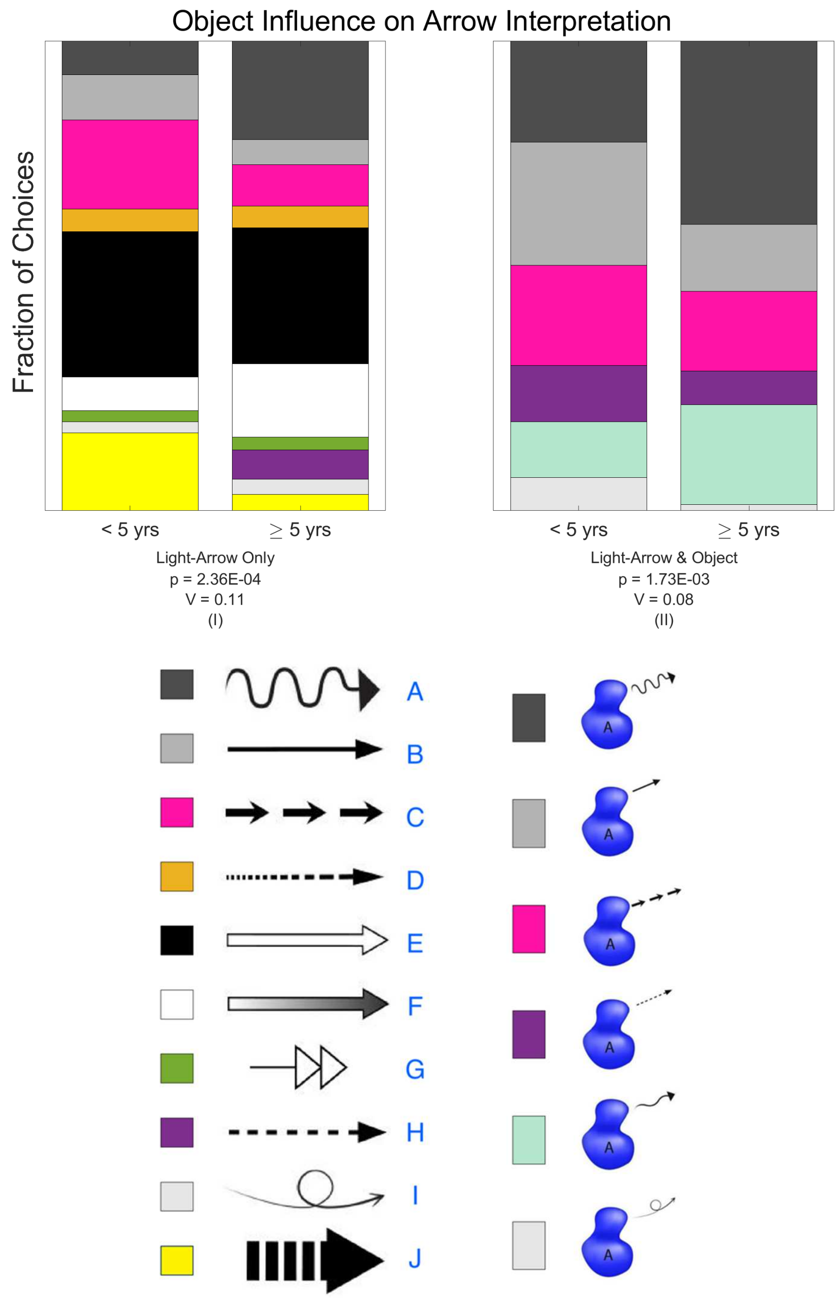


Figure 4.Compare arrow-only vs. contextual arrows in relation to language effect.

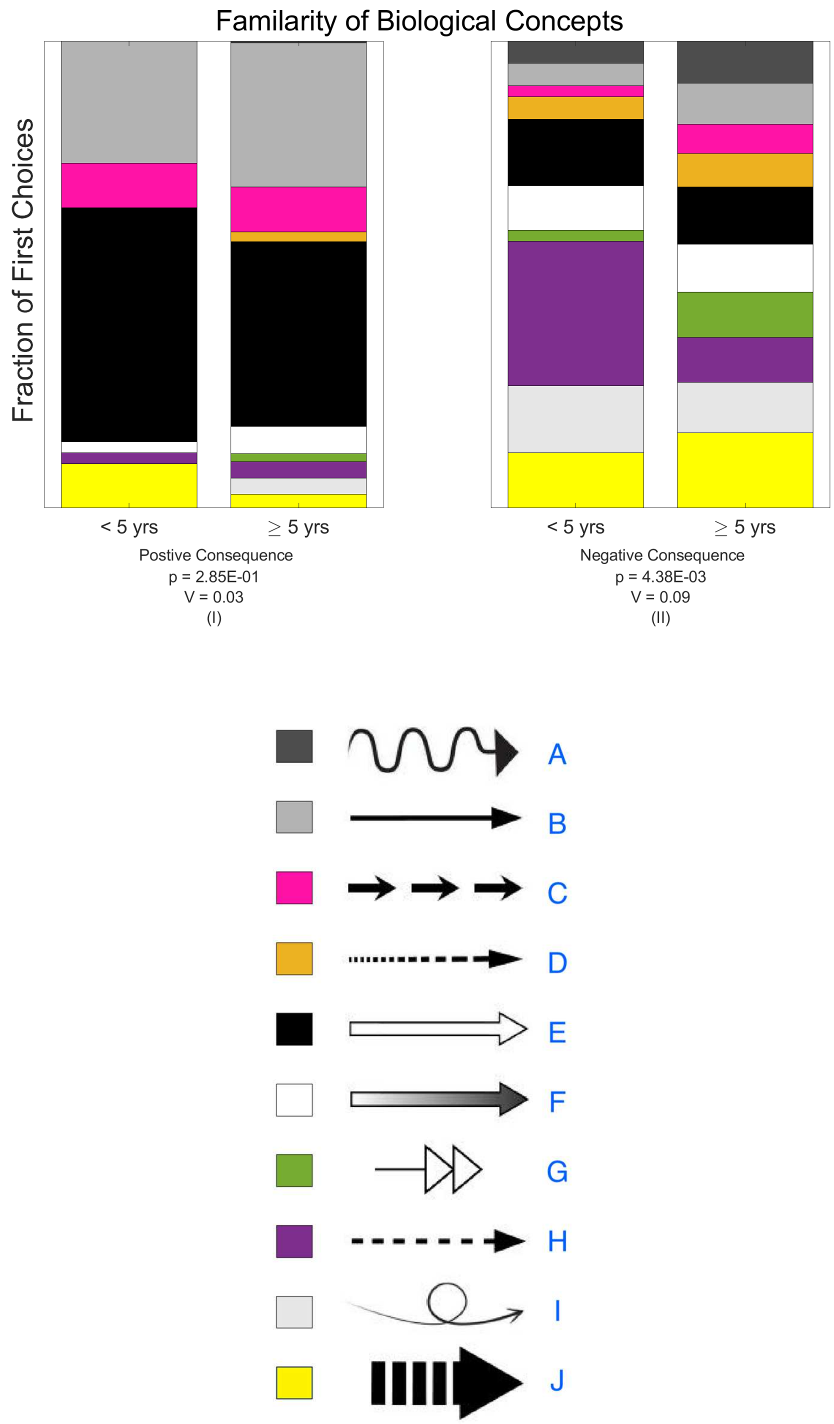


Figure 5. Compare familiar vs. unfamiliar concepts in relation to language effect.

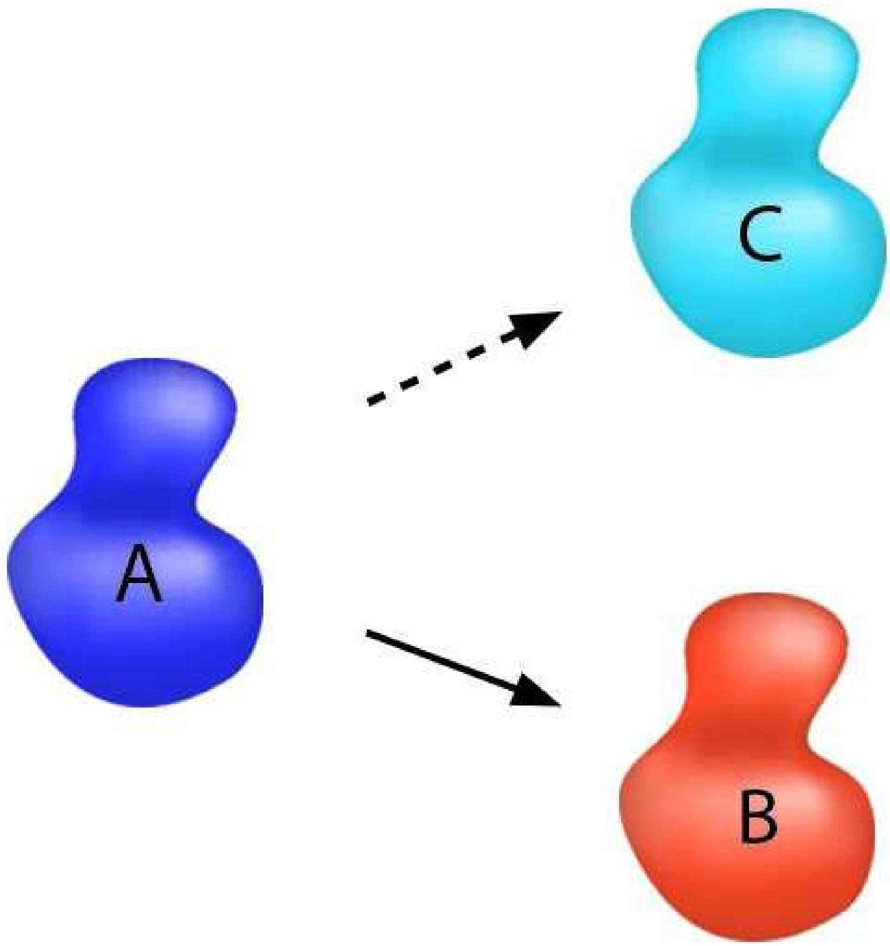


Figure 6. Diagram of the question analysed in figure 7.

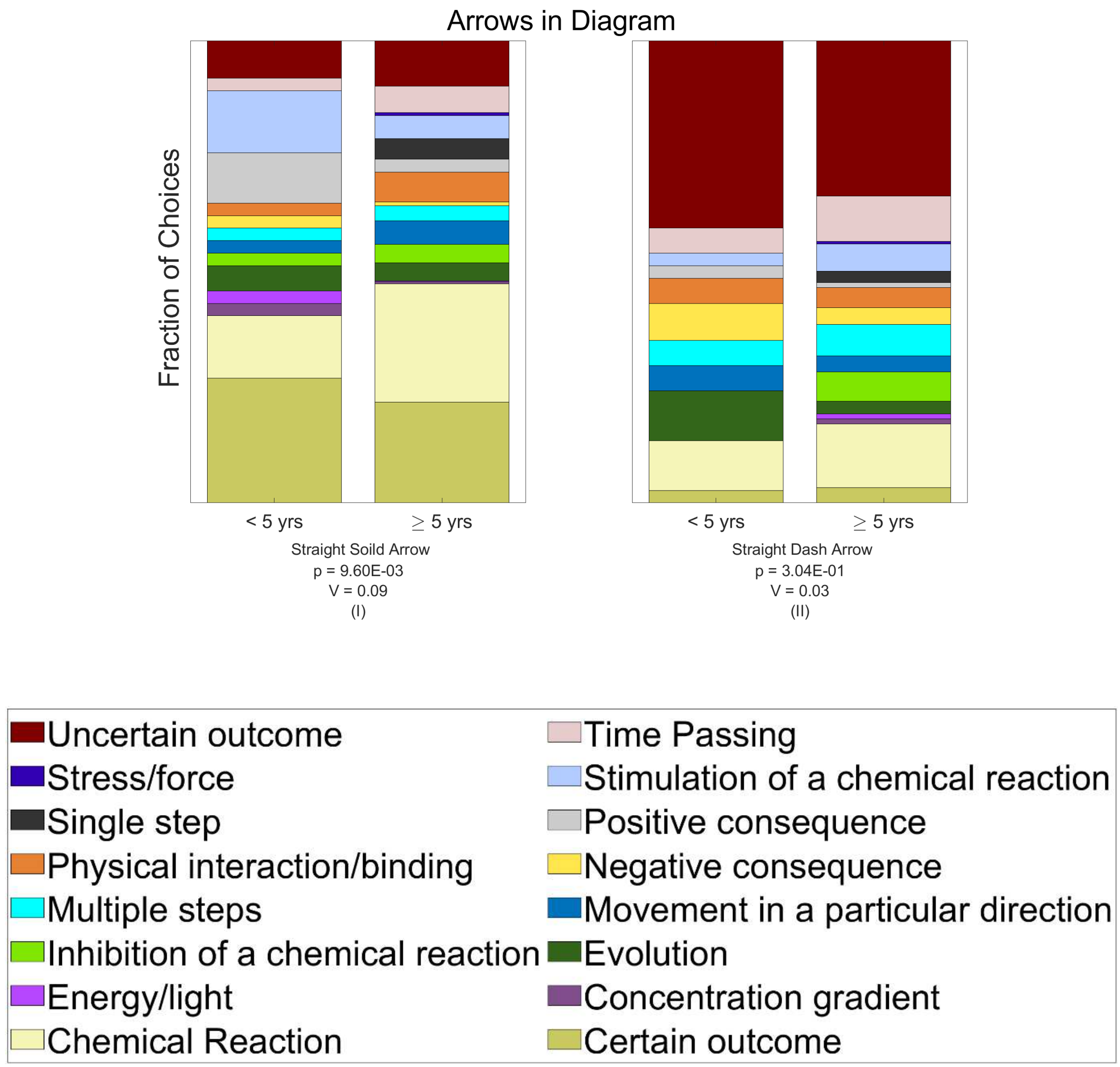


Figure 7. Compare primary vs. secondary arrows in relation to language effect.

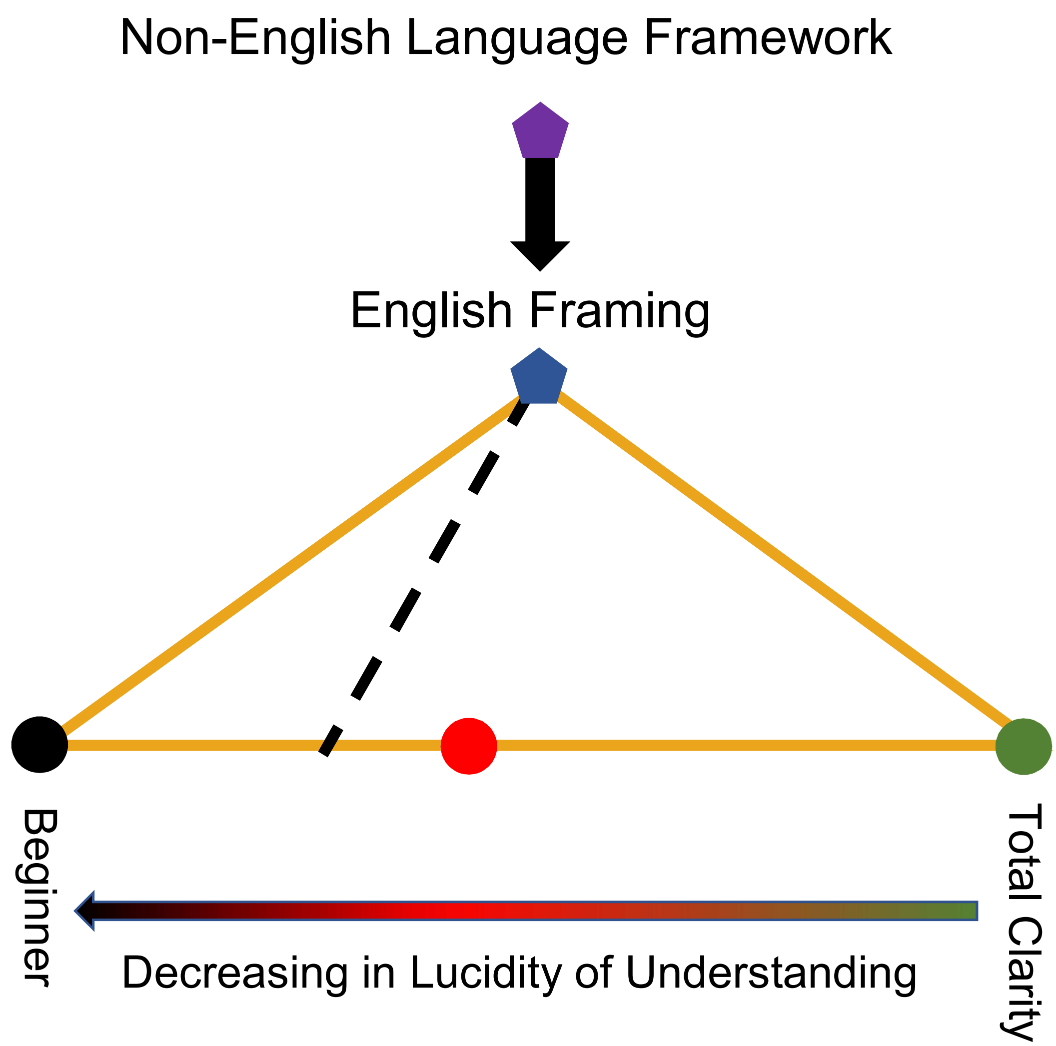


Figure 8. CHAT mediation of language framework.

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