Enhancing EFL Vocabulary Acquisition Through Computational Thinking

Youjun Tang[1,2](✉) and Xiaomei Ma[1]

[1] Xi'an Jiaotong University, Xi'an 710049, Shannxi, China
qdbhxytyj@126.com, xiaomei@xjtu.edu.cn
[2] Qingdao Binhai University, Qingdao 266555, Shandong, China

Abstract. The emergence of ChatGPT marks the advent of the era of artificial intelligence (AI) and language intelligence (LI). Moreover, the essence of AI and LI is a kind of deep machine learning based on computational thinking (CT). Computational thinking is rooted in computer science and is higher-order thinking that mimics how computers solve problems. At the same time, CT, a concept computer scientists propose, is also human thinking. Given factors such as the inconsistent definition of CT, the integration of CT into foreign language education in China has only just begun. In order to improve the vocabulary richness in English short essay writing of our non-English majors, we followed the critical skills of CT (data analysis, pattern recognition, abstraction, decomposition, and parallelization) to intervene in students' English vocabulary acquisition. We measured their short essay writing before and after the intervention using Quantitative Index Text Analyser (QUITA) software. The results showed that all vocabulary-related quantitative indexes changed significantly and that CT could facilitate Chinese students' English vocabulary acquisition efficiency. This study has implications for the new direction of foreign language education in China in the artificial and language intelligence era.

Keywords: Artificial Intelligence · Language Intelligence · Computational Thinking · EFL Vocabulary Acquisition

1 Introduction

1.1 ChatGPT and its Essence

The emergence of ChatGPT, an intelligent chatbot, marks that the information society has entered an epoch-making period of human-computer interaction and marks that education informatization has reached a deep integration of disciplines and information technology.

ChatGPT is the hottest intelligent chat tool and a recent research hotspot in linguistics. With its high text generation ability and smooth human-computer interaction capability, it has once again brought artificial intelligence (AI) into the focus of various research fields. In essence, ChatGPT is a natural language processing model that belongs to the application of generative artificial intelligence technology [1]. It also means the advent of the era of language intelligence (LI).

F. Zhao and D. Miao (Eds.): AIGC 2023, CCIS 1946, pp. 70–82, 2024.
https://doi.org/10.1007/978-981-99-7587-7_6

1.2 Thinking of AI and LI

Artificial intelligence (AI) refers explicitly to "a new technical science that studies and develops theories, methods, technologies, and application systems that can simulate, extend, and expand human intelligence. The purpose of the research is to promote intelligent machines that can listen (speech recognition, machine translation), see (image recognition, text recognition), speak (speech synthesis, human-machine dialogue), think (human-machine games, theorem proving), learn (machine learning, knowledge representation), and act (robotics, autonomous driving)" [2].

Language intelligence (LI) is one of the critical technologies that need to be concentrated in the current research of AI, and the breakthrough of its basic theory and essential technology research is of great significance to the development of AI in China. Linguistic intelligence, the intelligence of linguistic information, uses computer information technology to imitate human intelligence and analyze and process human language [3]. The purpose is to realize human-computer language interaction [4] eventually.

AI and LI are both manifestations of deep, autonomous machine learning. Its essence is automatic processing and processing based on the working principles of computers, ultimately solving problems. In this way, AI and LI follow computational thinking (CT), the embodiment of the computer way of thinking.

1.3 Computational Thinking (CT)

In 1980, Papert introduced the term "computational thinking" to refer to a model in which students use computers to improve their thinking [5]. In 1996, he re-emphasized the need for students to use computers to change their learning and improve their ability to express their ideas [6]. In 2006, Professor Jeannette M. Wing published a paper entitled "Computational Thinking," which, for the first time, defined CT as a universal attitude and skill and interpreted CT as a class of solutions that allow people to think "like computer scientists" [7]. In 2008, she gave a new interpretation of CT, stating that CT is essentially analytical thinking and that its three aspects of problem-solving, system design and evaluation, and understanding of intelligence and human behavior converge with mathematical thinking, engineering thinking, and scientific thinking, respectively [8]. Since then, the conceptual interpretation and teaching practice of CT have shown apparent diversity, and the academic community has yet to reach a consensus on CT.

Although there is no consensus on the definition of CT and what it encompasses, there is a consensus in the academic community that CT is higher-order thinking that imitates computer thinking to solve problems, is one of the essential qualities necessary for international talents in the 21st century, and is a vital tool for optimizing the way knowledge is acquired [9–12]. CT is both machine thinking and a concept proposed by computer scientists; therefore, CT is also human thinking, and the two can be mutually reinforcing. In the era of AI and LI, CT can contribute wisdom to the new direction of foreign language education.

1.4 Research Questions

Foreign language education in China faces opportunities and challenges in the era of AI and LI. As the common thinking of AI and LI, the intervention of CT in foreign language education may bring surprises.

English short essay writing is difficult for Chinese non-english majors, and its central problem lies in the poor English vocabulary of students in short essay writing, with many repetitive words and few advanced words. It is because students need help acquiring English vocabulary and acquire it inefficiently. Based on this, this study uses a sandwich intervention to intervene in CT in English vocabulary acquisition. It aims to address the following three questions:

(1) How does computational thinking intervene in English vocabulary acquisition?
(2) How does computational thinking affect English vocabulary acquisition?
(3) What is the role of computational thinking in vocabulary intervention?

2 Methods

2.1 Quasi-experimental Design

According to the needs of the study, we adopted a quasi-experimental design, i.e., the research process consisted of three main stages, including a pre-test, an instructional intervention based on the primary skills steps of CT, and a post-test. The study involved two natural classes, i.e., the experimental and control classes. According to Mackey and Gass, the experimental class engaged in a stepwise instructional intervention based on the formation of practical skills in CT. In contrast, the control class received the traditional instructional model of direct transfer of vocabulary memory [13]. In other words, the independent variable was the stepwise instructional intervention model based on the formation of the primary skills of CT. At the same time, English vocabulary mechanical memory that occurred in English learners' English writing in the control class was the dependent variable.

2.2 Experimental Conditions

The study was conducted in a private university with a teaching class that included at least 30 students; the course under study was college English writing with tiered instruction, and the study lasted for ten weeks, 90 min each.

2.3 Participants

Ninety-two freshmen from the class of 2021 participated in the study, with 46 students in each natural class. It means that the experimental class was homogeneous with the control class: from the same grade, at the same level of instruction, and in the same course. These students were between the ages of 18 and 21 and involved 11 majors, such as preschool education, mechanics, electronics, and international trade, with similar gender ratios. Before enrollment, all students had taken the college entrance exam, meaning they had at least ten years of English language learning experience. To verify the homogeneity of the participants, all students took a short essay writing pre-test, and the results showed that students' short essay writing in English generally lacked advanced vocabulary and vocabulary richness.

2.4 Assessment Tools

Test. Since students were required to take the National English Language Proficiency Test (NELPT), we organized a pre-test and a post-test, respectively, using questions from the June and December 2020 exams, as shown in Figs. 1 and 2 for more information:

Part I. Writing (30 minutes)

Directions: For this part, you are allowed 30 minutes to write an essay on the use of translation apps. (at least 150 words).

Fig. 1. Writing test in pre-test (June, 2020)

Part I. Writing (30 minutes)

Directions: In this section, you are allowed 30 minutes to write a short essay commenting on the saying "Learning is a daily experience and a lifetime mission." (at least 150 words).

Fig. 2. Writing test in post-test (December, 2020)

Instrument. All the essays in the research were measured using Quantitative Index Text Analyzer (QUITA) software, a free software designed and developed by the linguistics faculty and students at Palacky University, Czech Republic. QUITA is available for download at http://oltk.upol.cz/software or https://kcj.osu.cz/wp-content/uploads/2018/06/QUITA_Setup_1190.zip.

Quantitative Text Indexes. Some quantitative text indexes are needed to check the vocabulary. All indexes used in this research come from Haitao Liu's *An Introduction to Quantitative Linguistics* (2017) [14]. Twenty-two quantitative text indexes are briefly introduced in Liu's book. In this research, however, we only applied four of the most frequently used vocabulary-related indexes, including TTR, R1, Descriptivity, and Verb Distances. Table 1 below shows the relevant details for the four indexes.

Raters. The scorers were the researcher and another teacher with extensive experience in teaching writing. The two raters independently used QUITA to measure all students' essays on relevant vocabulary indexes, organized consistency tests, and discussed and agreed on disagreements.

Table 1. Brief introduction of the principal quantitative indexes related vocabulary.

Quantitative indexes	Brief introduction of the principal quantitative indexes
TTR	Token/type ratio: The ratio between the total number of word types (V) and that of word tokens (N) [15, 16] and an index on lexical diversity [17]
R_1	Relates to the vocabulary's richness, esp. The richness of made-up words [18]
Descriptivity	Refers to the degree of descriptivity in the form of adjectives/verbs + adjectives [14, 19]
Verb Distances	Implies the distance between the two neighbor verbs in a sentence or neighbor sentences [14, 19]

2.5 Intervention Process

The control group received the traditional direct instruction method, which teaches students to memorize English vocabulary by reading words aloud and then directly. In contrast, the experimental group experienced a 10-week stepwise dynamic assessment interventionist based on the formation of core skills in CT, which was divided into three main phases: pre-test, intervention, and post-test, but administered as a whole, also called sandwich dynamic assessment interventionist [20]. The main elements of these three phases are as follows:

Phase 1: Pre-test. The pre-test was used to obtain data on vocabulary measures for both classes and diagnostic information on short-text writing.

Stage 2: Mediation through instructional intervention. Based on the diagnostic information obtained from the pre-test, the researcher organized the experimental group to participate in a stepwise intervention teaching practice based on forming core CT skills to mediate the learners. Specifically, English words are viewed as a numerical symbol, and students are expected to abstract the form of word formation and its origin based on the critical skills of CT. This study adopts Tang and Ma's core step model of CT, which involves crucial skills, including data analysis (seeing words as numbers, symbols, or codes), pattern recognition (looking for commonalities, regular usage, patterns, and features), abstraction (distilling data to form procedural knowledge), decomposition (breaking down complex problems into more solvable or operational subproblems that can be multi (decomposing complex problems into easier-to-solve or easier-to-handle sub-problems that can be decomposed at multiple levels), and parallelization (parallel thinking, point by point, touch by touch, and networked mind maps) [21]. The steps for using CT to reinforce the memorization of English words are shown in Table 2:

Table 2. Step-by-step intervention on English vocabulary acquisition based on CT.

Steps	Data analysis	Pattern recognition	Abstraction	Decomposition	Parallelization
Operations	1. select target vocabulary from the textbook; 2. Ask learners to observe these target words carefully	1. Marking common parts in English words; 2. Asking learners to pay attention to the location of common forms and their forms; 3. Finding all words in the textbook that have similar structures	1. Rewrite all English words (coding), replacing English words with numbers, symbols or root words; 2. Focus on possible patterns of word formation or patterns of production	Simplify complex problems, improve the efficiency of problem solving by breaking them down in layers, reduce the difficulty and enhance the operability	Observe each word carefully and then associate it with the word you are most familiar with from the perspective of root affixes, word conversions, fixed collocations, habitual usage, and morphological similarities to form the broadest coverage mind network map possible
Targets	Guiding learners to focus on vocabulary formation methods that are characteristic of English thinking	Further help learners to enhance their awareness of the differences between English and Chinese vocabulary structures	Students are guided to gradually abstract word formation based on common root words and affixes: English words have their own specific historical origins and each of the 26 letters has its own specific basic meaning; English words are generally made up of roots plus prefixes and suffixes	The core question "How can I learn English vocabulary efficiently?" can be broken down into smaller questions. Can be broken down into smaller questions, such as: What are the common roots in English affixes? What are the common prefixes or suffixes, etc.? Then break it down until it is manageable for the individual learner	Expand your vocabulary by carefully analyzing each word and gradually associating, enriching, and expanding it layer by layer through computational thinking skills to form more and more category-based vocabulary network maps

For example, when we encounter the new word “Pose” in the textbook, the intervention can be listed as follows:

- Data analysis (The first step: Input words in the form of data or signs)

The instructor intends to find out the relevant words related to “Pose” in the textbook and lists them as follow:

apposite apposition
component compose composition compound
depose deposit discompose dispose disposition
exponent expose exposition expound
impose imposition impound
pose position positive propone proponent proposal propound preposition purpose
repose repository

- Pattern recognition through decomposition (Step two: Find commonalities in the structure of these words by breaking them down)

The instructor guides the students to decompose all the words listed above. They may be presented in the form below after decomposition.

ap+pos+i+te=apposite proper; ap+pos+i+tion=apposition juxtaposed, congruent; com+pon+ent=composed; part; parts; com+pos+e=compose, create; make; calm; com+pos+i+tion= composition composition; combination; composition; com+pound=compound compound; compounding; compound word; compounded; de+pos+e=exempt; precipitate; testify; de+pos+i+t=deposit store; pile; deposit; mineral deposit; heap; deposit; dis+com+pos+e= decompose to unsettle; dislocate; panic; de+com+pos+i+tion=decomposition to disintegrate; dis+pos+e=dispose to dispose of, remove, destroy; arrange; arrange; dis+pos+i+tion=disposition disposition; arrangement; ex+pon+ent= exponent explainer; ex+pos+e=expose expose; reveal; ex+pos+i+tion=exposition explain; elaborate; fair, exposition ex+pound=expound detail

im+pos+e=impose imposes; tax; im+pos+i+tion=imposition tax; impose; im+pound=impound to put... Enclose; impound; pos+e=pose cause; raise (a question, etc.); pose; pos+i+tion=position position; position; post; pos+i+tiv+e=positive affirmative; positive; optimistic; masculine; post+pon+e=postpone postpone; pro+pon+e= propone propose; propose; pro+pon+ent=proponent proposer; proponent; pro+pos+al=proposal proposer; proposal; proposal; proposal; pro+pos+e=propose proposal; proposal; pro+pround=propound propose; pur+pos+e= purpose purpose re+pos+e=repose rest; sleep; re+pos+i+tory=repository warehouse

- Abstraction (The third step: Summarize the commonalities; abstract the patterns of word formation)

  Lead students to gradually abstract the results of:

  (1) English words are formed by word roots plus prefixes or with suffixes;
  (2) Pon, pound, pos(it) = to put, to place put, place;
  (3) Common prefixes: ap, com, de, dis, ex, im, pro, pur, re;
  (4) Common suffixes: tion, ent, tive, al, tory

- Decomposition (The forth step: Decompose the problems resulted from the abstraction to make them easier and more accessible)

In this case, the question arises: How can we acquire English vocabulary through words plus prefixes or suffixes? It seems complicated for the Chinese learners. So it can be decomposed as the following questions:

(1) What are the common roots in English words?
(2) What are the common prefixes in English words?
(3) What are the common suffixes in English words?

Of course, these questions can be further decomposed depending on the different cognitive levels of different learners.

- Parallelization (The fifth step: A new word is associated with a related word that is most familiar to the learner, and then related according to word formation, fixed monogram, morphological similarity, and word conversion, forming a neural network-like mind map).

In this case, parallelization may help the learners form the following word mind map (Fig. 3).

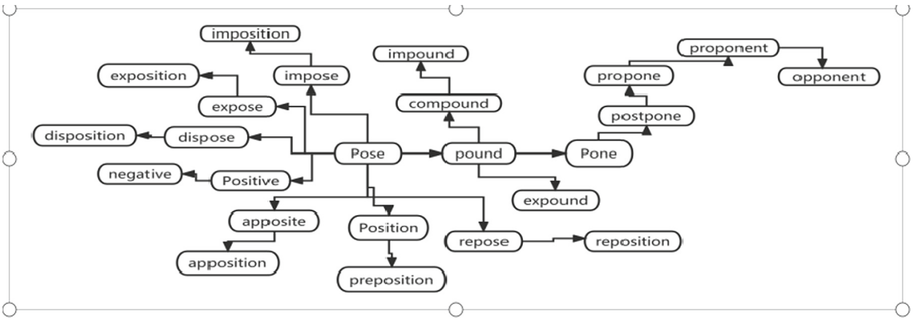

Fig. 3. "Pose" related words mind map based on parallelization

Of course, this mind map belongs to the first level of mind mapping, and according to parallel thinking, it can continue to expand and extend more vocabulary.

In this way, we repeat the intervention numerous times, and the learners should draw vocabulary mind maps as many as possible at the end of the intervention period.

Stage Three: Post-test. After ten weeks of instructing a dynamic assessment step-by-step intervention based on the formation of core skills in CT, we organized timely post-test writing.

2.6 Data Collection and Processing

We used QUITA software to measure the relevant quantitative indexes from the pre-test and post-test essays of the learners and conducted independent sample t-tests and paired sample t-tests by SPSS23 to observe the effects and changes brought about by the intervention.

3 Results

3.1 Comparison Between the Experimental Class and Control Class

The control class received the traditional intervention model. The learners just memorized the target words through reading, writing, and memorizing. In comparison, the experimental class embraced the CT-based intervention. Both groups attended the pre-test and post-test. Tables 3 and 4 show the results:

Table 3. Results of quantitative indexes related to vocabulary from the pretest.

	Control class (n = 46)		Experimental class (n = 46)		MD	t(45)
	M	SD	M	SD		
TTR	0.524	0.830	0.523	0.847	0.0004	0.024
R1	0.788	0.058	0.787	0.057	0.0009	0.078
V.D.	8.834	6.202	8.580	5.650	0.253	0.205
Des.	0.315	0.077	0.316	0.076	-0.0003	-0.020

$P > 0.05$ $P > 0.05$ $P > 0.05$ $P > 0.05$.

Table 4. Results of quantitative indexes related to vocabulary from the post-test.

	Control class (n = 46)		Experimental class (n = 46)		MD	t(45)
	M	*SD*	*M*	*SD*		
TTR	0.527	0.076	0.586	.075	-0.059	-3.767**
R1	0.785	0.048	0.689	0.048	0.095	9.523**
V.D.	8.679	5.651	6.910	4.629	1.769	1.643**
Des.	0.311	0.067	0.257	0.044	0.053	4.511**

** $P<0.01$ ** $P<0.01$ ** $P<0.01$ ** $P<0.01$

Table 3 clearly shows no significant difference between the means of the control and experimental groups regarding the quantitative indexes related to vocabulary in the pre-test. In contrast, Table 4 distinctly shows that the means of all measures in the post-test were significantly different, indicating that the control group did not change significantly after traditional vocabulary instruction, while the experimental group changed significantly, and students' vocabulary richness was enhanced.

3.2 The Experimental Class

All the learners from the experimental group received a 10-week intervention based on CT. Table 5 below demonstrates the outcome data of the experimental group after paired samples t-test.

Table 5 indicates that all the means from the post-test are significantly different from those of the pre-test, which means the intervention approach to vocabulary acquisition works. All the learners can improve their EFL vocabulary acquisition performance.

3.3 The Control Class

To check the effects of the traditional approach to EFL vocabulary acquisition, we also tested the quantitative indexes related to the control group from both the pre-test and post-test. Table 6 lists the results:

Table 5. Results of quantitative indexes related to vocabulary from the experimental class.

	Pre-test (n = 46)		Post-test (n = 46)		MD	t(45)
	M	*SD*	*M*	*SD*		
TTR	0.524	0.084	0.586	0.075	-0.063	-10.660**
R1	0.787	0.057	0.689	0.048	0.098	19.751**
V.D.	8.581	5.651	6.910	4.629	1.671	8.153**
Des.	0.315	0.077	0.257	0.044	0.058	9.367**

** P<0.01 ** P<0.01 ** P<0.01 ** P<0.01

Table 6. Results of quantitative indexes related to vocabulary from the control class.

	Pre-test (n = 46)		Post-test (n = 46)		MD	t(45)
	M	*SD*	*M*	*SD*		
TTR	0.524	0.083	0.527	0.075	-0.003	-1.444
R1	0.788	0.058	0.785	0.048	0.003	1.082
V.D.	8.834	6.202	8.679	5.651	0.155	1.278
Des.	0.315	0.077	0.311	0.667	0.004	1.298

$P > 0.05$ $P > 0.05$ $P > 0.05$ $P > 0.05$.

Table 6 illustrates that all the means from the post-test are not significantly different from the pre-test data. It denotes that the traditional ways of EFL vocabulary acquisition do not initiate improvement.

4 Discussion

4.1 How Does Computational Thinking Intervene in English Vocabulary Acquisition?

The traditional ways of English vocabulary acquisition are closely related to reading, writing, and memorizing. This study shows the low efficiency of the traditional ways of English vocabulary acquisition. To change the status quo, we followed the primary skills of CT step-by-step to intervene in students' vocabulary memorization. The data show that this new approach is efficient, practical and expands students' vocabulary in a short time. Using higher-order thinking, such as data analysis, pattern recognition, abstraction, decomposition, and parallelization, allows learners to understand English word formation patterns gradually. Word-to-word associations are achieved from the perspectives of root word affixation, word conversion, word similarity, fixed collocations, and regular usage, resulting in many vocabulary network diagrams that visualize and memorize more words.

CT works in EFL vocabulary acquisition in that the new way agrees with the Theory of Prototypes [22]. Prototypical category theory advocates the centrality of prototypical categories, the key to which is finding category similarities. Many words already exist in the learner's brain, which the learner has mastered and is familiar with. The role of computational thinking is to guide learners to find members related to this category through higher-order thinking. Computational thinking intervenes in vocabulary acquisition and is consistent with the cognitive psychology of learners.

4.2 How Does Computational Thinking Affect English Vocabulary Acquisition?

CT, higher-order thinking, can help the learners focus on the form of the words. They follow the CT-based step-by-step model to solve all problems before vocabulary acquisition. The critical role of computational thinking in this study is to help learners make influential associations between different words in line with the learners' cognitive mechanisms.

In this study, computational thinking helps learners re-categorize and re-categorize new words in their textbooks to accumulate more relevant vocabulary. This method is more effective than the traditional method. It is more in line with learners' cognitive patterns, which can effectively enhance vocabulary richness in learners' English compositions and add more advanced vocabulary.

4.3 What is the Role of Computational Thinking in Vocabulary Intervention?

CT, in this study, is a thinking bridge. It has become an effective intervention tool. CT links the new vocabulary with the prototype words in the learners' brains. In this way, the learners come to build up more and more vocabulary patterns or categories. Gradually, learners can accumulate new words or phrases.

In the era of big data, information technology, and artificial intelligence, computational thinking has been recognized as an essential educational technology, a basic talent competitiveness literacy, and, more importantly, a symbolic mediating tool [21, 23, 24]. In the present study, the central core skills of computational thinking have been transformed into sociocultural symbolic tools that mediate prior learning (memorization of vocabulary knowledge) and higher levels of learning of learners and play a critical mediating role in forming learners' higher-order thinking.

5 Conclusion

The present study further illustrates that computational thinking can strengthen learners' English vocabulary acquisition. It also validates the positive role of computational thinking in foreign language education [25]. Also, dynamic assessment theory, especially the sandwich intervention, enhanced the teaching intervention in large classes [26].

CT is the fundamental way of thinking in AI and LI, reflecting both the characteristics of machine thinking and the attribute features of human thinking. This kind of higher-order thinking has an essential inspirational role in foreign language education and teaching in the era of big data and AI.

References

1. Hu, G.S., Qi, Y.J.: Foreign language education in China in the era of ChatGPT: seeking change and adaptation. Technol. Enhan. Forei. Lang. **209**(1), 3–6 and 105 (2023)
2. Tan, T.N.: The History, Present and Future of Artificial Intelligence. [EB/OL] (2019). Retrieved from http://ia.cas.cn/xwzx/mtsm/201903/t20190311_5252250.html
3. Zhou, J.S., Lv, X.Q., Shi, J.S., Zhang, K.: Research on linguistic intelligence is becoming a hot topic. China Social Science News (Feb. 17, 2017)
4. Hu, K.B., Tian, X.J.: Cultivation of MTI talents in the context of language intelligence: challenges, countermeasures and prospects. Foreign Language World **2**, 59–64 (2020)
5. Papert, S.: Mindstorms: Children, computers, and powerful ideas, 285–286. Basic Books, New York (1980)
6. Papert, S.: An exploration in the space of mathematics education. Int. J. Comput. Math. Learn. **1**, 95–123 (1996)
7. Wing, J.M.: Computational Thinking. Commun. ACM **49**(3), 33–35 (2006)
8. Wing, J.M.: Computational thinking and thinking about computing. Philosophical transactions of the royal society of London: Mathematical, Physical and Engineering Sciences **366**(1881), 3717–3725 (2008)
9. Papert, S.: You can't think about thinking without thinking about thinking about something. Contempor. Issu. Technol. Teach. Edu. **5**(3), 366–367 (2005)
10. Barr, V., Stephenson, C.: Bringing computational thinking to K-12: What is involved and what is the role of the computer science education community? Acm Inroads **2**(1), 48–54 (2011)
11. Jona, K., et al.: Embedding computational thinking in science, technology, engineering, and math (CT-STEM). In: a paper presented at the future directions in computer science education summit meeting. Orlando, FL (2014)
12. Lee, I., et al.: Computational thinking for youth in practice. Acm Inroads **2**(1), 32–37 (2011)
13. Mackey, A., Gass, S.M.: Second language research: Methodology and design. Erlbaum (2005)
14. Liu, H.T.: An introduction to quantitative linguistics. The Commercial Press, Beijing (2017)
15. Jockers, M.L.: Text analysis with R for students of literature. Springer, Switzerland (2014)
16. Laufer, B., Nation, P.: Vocabulary size and use: Lexical richness in L2 written production. Appl. Linguis. **16**(3), 307–322 (1995)
17. Xian, W., Sun, S.: Dynamic lexical features of Ph.D. theses across disciplines: a text mining approach (2018)
18. Popescu, I.-I., Ĉech, R., Altmann, G.: Some geometric properties of Slovak poetry. J. Quantit. Linguis. **2**, 121–131 (2012)
19. Kubát, M., Matlach, V., Ĉech, R.: QUITA. RAM-Verlag, Quantitative Index Text Analyzer. Lüdenscheid (2014)
20. Poehner, M.E.: A casebook of dynamic assessment in foreign language education. CALPER publications, The Pennsylvania State University (2018)
21. Tang, Y.J., Ma, X.M.: Computational thinking: A mediation tool and higher-order thinking for linking EFL grammar knowledge with competency. Thinking Skills and Creativity **46**(4), 101143 (2022)
22. Wang, Y.: Cognitive Linguistics, 1st edn. Shanghai Foreign Language Education Press, Shanghai (2007)
23. Nouri, J., Zhang, L., Mannila, L., Norén, E.: Development of computational thinking, digital competence and 21st century skills when learning programming in K-9. Educ. Inq. **11**(1), 1–17 (2020)
24. Acevedo-Borrega, J., Valverde-Berrocoso, J., Garrido-Arroyo, M.D.C.: Computational thinking and educational technology: a scoping review of the literature. Education Science **12**(39) (2022)

25. Tang, Y.J., Ma, X.M.: Can computational thinking contribute to EFL learning and teaching?. In: 2023 International Conference on Artificial Intelligence and Education (ICAIE), pp. 20–24. Kobe, Japan (2023). https://doi.org/10.1109/ICAIE56796.2023.00016
26. Tang, Y., Ma, X.: An interventionist dynamic assessment approach to college english writing in China. Lang. Assess. Q. (2022). https://doi.org/10.1080/15434303.2022.2155165