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A review of theories, pedagogies and vocabulary learning tasks of English vocabulary learning apps for Chinese EFL learners

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Abstract: Among a growing body of mobile-assisted-language-learning (MALL) studies, vocabulary application (app) studies have comprised an unprecedented proportion. However, there has been insufficient discussion about the fundamental language learning theories and pedagogies underlying app design. This study aims to fill this gap by conceptualising and theorising the design of English vocabulary learning apps with a focused analysis of their task features with relation to vocabulary learning strategies (VLS), language learning theories and pedagogies. Four Chinese–English vocabulary learning apps were purposively sampled. The results show that the design of the four evaluated apps incorporates principles from four distinct language learning theories: behaviourism, input-based emergentism, sociocultural theory and information and cognitive processing theories. The four apps’ tasks and user interfaces were analysed to generate codes for task classification. These task-related codes were further classified under the categories of Schmitt’s VLS taxonomy and under pedagogical categories based on the definitions of pedagogies and VLS codes and the intended classroom practice. Vocabulary pedagogies were further linked with theories to shed light on the theoretical foundations for the apps’ use of learning tasks and VLS as well as on the pedagogical prospects of vocabulary learning apps.

Keywords: mobile-assisted language learning; mobile-assisted vocabulary learning; vocabulary learning strategies; language learning theories; language learning pedagogies

1 Introduction

As a basic linguistic building block, vocabulary is critical to mastering any language, and a lack of vocabulary knowledge will undermine comprehension and utilisation (Nation, 2001; Song & Fox, 2008). The prominence of English as a global language led

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to the proliferation of English vocabulary learning applications (apps) following the advent of smartphones in 2007 (Zhang & Pérez-Paredes, 2019). Mobile-assisted vocabulary learning (MAVL), as part of mobile-assisted language learning (MALL), is able to situate language learning in authentic, social and contextual conditions (Kukulska-Hulme, 2009), and the growing use of mobile devices is generating more non-formal (out of the classroom) language learning opportunities (Kukulska-Hulme, 2009). Moreover, in the post-pandemic era, vocabulary apps have become increasingly indispensable to remote English learning.

The majority of MALL studies focus on the design issues and the effectiveness of content delivery (Kukulska-Hulme & Shield, 2008). However, few studies have compared different English vocabulary apps to illuminate not just their learning outcomes, but also the theories, pedagogies and vocabulary learning strategies (VLS) underlying their designs. Historically, the field of vocabulary instruction and learning has been influenced by various language learning pedagogies (Jamal, 2016). The rationale for investigating theories stems from the recognition that a structured and effective exploration of second language (L2) learning is only possible when guided by theoretical frameworks (Mitchell et al., 2019). For app developers, the pedagogical approaches and VLS of vocabulary apps should be grounded in language learning theories that have undergone extensive scrutiny and collaborative examination and have evolved through systematic inquiry supported by empirical evidence (Mitchell et al., 2019).

Meanwhile, learning strategies are important since learners use particular strategies in vocabulary acquisition much more frequently than in any other area of linguistic competency (Schmitt, 1997). Specifically, learners employ a variety of strategies to learn the meanings of new words, store and retrieve them in long-term memory, and utilise them (Catalan, 2003). Therefore, the selection of pedagogical approaches has a significant impact on the utilisation and implementation of VLS. In order for us to gain a deeper understanding of the interaction between VLS and vocabulary apps, both must be firmly grounded in a robust theoretical framework (Yang et al., 2021). Thus, the optimal benefits for EFL learners can be attained when apps draw from well-defined theories and pedagogies to inform users' learning experiences. VLS can thus accelerate vocabulary learning, solidify learners' vocabulary retention and make learners more responsible for their own learning.

This study aims to fill the gap by comparing English vocabulary learning apps and identifying good features that can be incorporated into app design to help students achieve effective learning. It does this by comparing four apps, conceptualising and theorising their designs via analysis of their task features with relation to VLS (based on Schmitt's VLS taxonomy) and the underlying theories and pedagogies. The apps are then classified into distinct categories. The study also aims to help maximise the potential and value of language learning apps in the post-pandemic era.

2 Literature review

2.1 Complexity of vocabulary learning

Words are not discrete units but are rather part of numerous interconnected systems and levels that give rise to the multidimensional and dynamic nature of vocabulary learning (Nation, 2001). Table 1 presents Nation’s (2001, p. 27) definition of vocabulary knowledge, which encompasses an understanding of form, meaning and use. Each aspect engages learners’ receptive and productive word knowledge. Receptive word knowledge involves comprehending the form of a word through reading or listening and being able to retrieve the word’s meaning. Productive word knowledge refers to the word forms that learners create through speaking and writing in communication with others (Nation, 2001).

Nation (2001) also suggested three psychological processes for effective vocabulary learning: noticing (a word is highlighted as being salient text input), retrieving (a word is encountered again) and generating (a previously encountered word is met or used in a slightly different way or context). This three-stage approach highlights the significance of the interaction between language input and output as well as

Table 1: What is involved in knowing a word (Nation, 2001, p. 27).

Form	Spoken	R What does the word sound like? P How is the word pronounced?
	Written	R What does the word look like? P How is the word written and spelled?
	Word parts	R What parts are recognisable in this word? P What word parts are needed to express the meaning?
Meaning	Form and meaning	R What meaning does this word form signal? P What word form can be used to express this meaning?
	Concept and referents	R What is included in the concept? P What items can this item refer to?
	Associations	R What other words does this make us think of? P What other words could we use instead of this one?
Use	Grammatical functions	R In what pattern does this word occur? P In what pattern must we use this word?
	Collocations	R What words or types of words occur with this one? P What words or types of words must we use with this one?
	Constraints on use (register, frequency...)	R Where, when, and how often would we expect to meet this word? P Where, when, and how can we use this word?

Note. In column 3, R, receptive knowledge, P, productive knowledge.

learners' generative application of freshly learned vocabulary in new circumstances (Wong & Looi, 2010).

Moreover, vocabulary learning is incremental, non-linear and dynamic. According to Henricksen (1999), word knowledge exists on a continuum, ranging from zero to partial to precise. Nagy and Scott (2000) supported this notion with their incrementality principle, which posits that word knowledge encompasses various levels of comprehension. Schmitt (2008) further described this continuum as starting with the explicit building of a form-meaning link and progressing to implicit, context-based vocabulary learning. The multidimensional and dynamic nature of vocabulary learning calls for targeted pedagogies and learning strategies to address different aspects of word knowledge and cater to learners at various vocabulary proficiencies (Schmitt, 2008).

2.2 VLS

VLS combine two important areas of language studies: vocabulary (Meara, 1987) and learner strategies (Schmitt, 1997). Research into language learning strategies examines how learners' actions, approaches and degree of control over their own learning might affect the learning processes and outcomes (Schmitt, 1997). As part of the array of language learning strategies, VLS are inspired by the intertwined areas of cognitive psychology and second language acquisition (SLA) (Kudo, 1999). O'Malley and Chamot (1990), both cognitive psychologists, extended Anderson's (1983) model of mental operation when acquiring a skill to the acquisition of language and vocabulary. According to the model they developed, vocabulary acquisition comprises three stages: the cognitive stage, the associative stage and the autonomous stage. Through this tripartite VLS, learners are able to transfer declarative knowledge to procedural knowledge, which contributes to their ability to build form-meaning links intentionally and utilise lexical items without awareness. In the field of SLA, early research on VLS was predominantly descriptive and was not influenced by cognitive psychology (Kudo, 1999). For example, Rubin (1987) and Naiman et al. (1978) subjectively categorised learners' language acquisition strategies based on interviews, classroom observations and diaries.

Previous studies have uncovered various VLS used by L2 learners (e.g., Brown & Perry, 1991; Fan, 2003; Gu & Johnson, 1996; Lawson & Hogben, 1996; Prince, 1996; Schmitt, 1997), finding that most VLS combine cognitive, psychological and SLA theories. Meanwhile, researchers have attempted to develop VLS taxonomies that group individual strategies. Oxford (1990) made one of the earliest attempts to offer a thorough overview of vocabulary acquisition techniques. She distinguished direct (memory/cognitive/compensation) and indirect (metacognitive/social/affective) strategies. Stoffer (1995) subsequently developed a VLS inventory that grouped 53 strategies into

nine categories. Nation (2001) categorised VLS by relating them to three vocabulary learning processes: planning vocabulary knowledge, accessing sources of vocabulary knowledge and establishing vocabulary knowledge.

Table 2 presents Schmitt’s (1997) comprehensive taxonomy of VLS, which further developed Oxford’s (1990) classification system and the VLS identified by other researchers (e.g. Cook & Mayer, 1983; Nation, 1990; Purpura, 1994). He classified strategies into two major categories: discovery of a new word’s initial information and the consolidation of a word once it has been encountered. The two categories comprise five sub-strategy groups, for which Schmitt (1997, p. 205) provided the following definitions: social strategies (SOC), which refers to ‘use of interaction with other people to improve language learning’; memory strategies (MEM) denote ‘approaches which relate new material to existing knowledge’; cognitive strategies (COG) ‘exhibit the common function of “manipulation or transformation of the target language by the learner”’ (Oxford, 1990, p. 42); metacognitive strategies (MET) ‘[involve] a conscious overview of

Table 2: Excerpts of Schmitt’s VLS taxonomy (Segler et al., 2002, p. 412).

Dimension	Discovery	Consolidation
Determination	Analyse part-of-speech Analyse affixes, roots Check for L1 cognate Guess from context Consult dictionary Use word lists	–
Social	Ask teacher Ask classmates Group work	Group study/practice Teacher checks word lists Interact with L1 speakers
Memory	–	Image of word meaning Connect to related words Group words together Study word sound/spelling Use physical action Use cognates Paraphrase word meaning Underline initial letter
Cognitive	–	Verbal/written repetition Note-taking Put L2 labels on subjects
Mate-cognitive	–	Use L2 media Test yourself Continue study over time Skip/pass new word

the learning processes and making decisions about planning, monitoring or evaluating the best ways to study'; determination strategies (DET) are mostly used for discovering a word's meaning at the first encounter by utilising language knowledge, contextual clues or reference materials. Schmitt (1997) also noted that several strategies could fit into multiple categories given their multidimensional functions.

Schmitt's taxonomy is seemingly the most extensive and most cited (e.g. Al-Omairi, 2020; Amirian & Heshmatifar, 2013; Asgari & Mustapha, 2011; Baskin et al., 2017; Duong et al., 2021; Rabadi, 2016; Segler et al., 2002) when compared to other classification schemes (e.g. Gu & Johnson, 1996; Oxford, 1990; O'Malley & Chamot, 1990; Stoffer, 1995). It also has the advantage of being structured around a recognised set of vocabulary acquisition processes (Segler et al., 2002). Furthermore, because Schmitt's VLS taxonomy was initially developed based on Japanese learners acquiring English as an L2, it has demonstrated its relevance and applicability in an EFL context. Given the limited number of recent VLS taxonomies proposed in the MAVL context, Schmitt's taxonomy has been chosen in this study to elucidate the VLS deployed in the four selected apps. It is also relevant that Schmitt's taxonomy has the potential to be further developed in the MAVL context by integrating contextual features and multimodal functions. The VLS that would previously have been implemented in the classroom with teachers and students must be adapted to suit the MAVL context, and the extent of collaboration and mediation offered by an app will likely influence the applicability of Schmitt's VLS taxonomy (Segler et al., 2002). Therefore, this study aims to both review the vocabulary tasks of the four selected apps and improve Schmitt's VLS taxonomy to extend its application in informal contexts. The study also aims to establish explicit links between the VLS in Schmitt's taxonomy, pedagogies and language learning theories.

2.3 MAVL

Vocabulary has been subject to extensive investigation in MALL research. Learning vocabulary using mobile platforms is generally referred to as mobile-assisted vocabulary learning (MAVL) (Okumuş Dağdeler, 2023). Studies on MAVL tend to focus on the following topics: vocabulary learning outcomes (e.g. Basoglu & Akdemir, 2010; Chen & Li, 2010; Hsu & Lee, 2011; Sandberg et al., 2014), students' learning experiences (e.g. Fageeh, 2013; Li, 2021; Rosell-Aguilar, 2015) and the evaluation of app design through academic achievement (e.g. Kearney et al., 2012; Rosell-Aguilar, 2017; Sung et al., 2015).

Okumuş Dağdeler's (2023) systematic review of MAVL literature found two common themes in the focus on language learning – vocabulary acquisition and users' perceptions – while for the focus on technology, gamification has frequently been examined empirically. Regarding learning experiences, some qualitative researchers

have sought to uncover learners' perceptions towards mobile vocabulary learning via self-reporting or questionnaires. For instance, Rosell-Aguilar and Qian (2016) investigated learners' perceptions of a Chinese character learning app developed by researchers themselves which were predominantly positive. The study indicated that this app placed less emphasis on productive skills. This aligns with Kim and Kwon's (2012) observation that most apps prioritise cognitive processes and receptive vocabulary knowledge, such as recall and comprehension of word meaning.

However, few studies have investigated VLS taxonomy in the context of MAVL. Of the small number that have investigated this issue, Segler et al. (2002) provided initial insights into the use of VLS in an intelligent computer-assisted language learning (ICALL) environment, with their analysis mainly based on Schmitt's (1997) VLS taxonomy. Their inquiry aimed to guide the development of a taxonomy specifically focused on VLS employed in an ICALL setting.

While ICALL shares similarities with MAVL, smart phones and smart applications in MAVL offer anytime-anywhere learning that reduces learning burden and enhances vocabulary learning (Daly, 2022). Daly (2022) compared the performance of 134 students using different VLS methods (a flashcard app, paper-based notes and wordlists and a combination of the two). The study found a positive correlation between the time spent using the flashcard app and the students' scores on vocabulary tests, demonstrating the effectiveness of integrating VLS with MAVL. However, Daly's study was limited to the use of flashcards, notes and wordlists, providing an incomplete overview of the VLS taxonomy and the learning materials on vocabulary apps.

Burston (2014) made the critique that most mobile language-learning materials simply replicate what has been done before with other technologies. In order to investigate and build on Burston's critique after nearly a decade, this study aims to offer comprehensive insights into vocabulary learning materials and strategies in the MAVL context.

2.4 Primary theories and theoretical trends in research on technology and SLA

Burston (2014) concluded that a fundamental problem in many MALL and MAVL studies is technocentricity, resulting in a lack of focus on pedagogical innovation. The fundamental cause of technocentricity is the neglect of theorisation, with only a very limited number of studies having scrutinised the theories and pedagogies that underlie app design. An exception is Ma and Yodkamlue (2019), who discussed the underlying theories behind a vocabulary app's design, including dual coding theory (DCT) (Paivio, 1971), cognitive theory of multimedia learning (CTML) (Mayer, 1997) and a memory-based strategic framework for vocabulary learning (Ma, 2014).

Yang et al. (2021) synthesised six strands of theories from previous theoretical frameworks underlying technology-assisted L2 vocabulary learning (see Alvermann et al., 2013; Samuels & Kamil, 2002; Tracey & Morrow, 2006), including behaviourism, constructivism, information and cognitive processing theories, social constructivism and sociocognitive theories. However, the theoretical frameworks that Yang et al. (2021) examined emphasise the application of cognitive and social-oriented learning theories in the field of reading research in general. Thus, the vocabulary learning pedagogies reviewed by Jamal (2016) were integrated to fit vocabulary learning to provide a primary theoretical reference to explore the theories underpinning the designs of selected vocabulary apps. Jamal discussed the vocabulary learning pedagogies that engage with behavioural-psychological methods, input-rich theoretical methodologies and communicative methods. Drawing on these works while also considering the comprehensive range of language learning theories synthesised by Mitchell et al. (2019), the following theories orientate this study: behaviourism, input-based emergentism, sociocultural theory (SCT) and information/cognitive processing theories.

Behaviourism. Behaviourists explain learning ‘in terms of imitation, practice, reinforcement (or feedback on success), and habit formation’ (Lightbown & Spada, 2013, p. 103). During L2 learning, learners imitate the teaching content and the language produced around them. They then reproduce what they have learned through external reinforcement, ultimately forming L2 learning habits.

Behaviourism-based pedagogies and VLS. Influenced by critics of behaviourist theories (e.g. Brooks, 1960; Lado, 1964), the audiolingual approach gained prevalence in classroom teaching with the aim of fostering students’ oral proficiency in the target language through speech imitation via listening (Lightbown & Spada, 2013). However, when using apps, learners have fewer opportunities to practise articulation and pronunciation, leading to limited phonological and word knowledge (Rosell-Aguilar, 2017). Even if learners imitate pronunciation by listening and shadowing, apps provide little corrective feedback. Empirical studies on classroom-based SLA suggest that students value teachers’ corrective feedback as it helps them internalise the target language and use it effectively (N. C. Ellis, 2002).

The grammar-translation approach, also influenced by behaviourism (Jamal, 2016), involves activities where students translate sentences and answer comprehension questions in their native language (L1) (Lightbown & Spada, 2013). Although this approach aims to enhance reading and writing abilities through translation, the L1–L2 paired translation equivalents in vocabulary acquisition highlight the critical role of the L1. On language learning apps, the emphasis shifts from mere translation of text to memorising paired translation equivalents in the learner’s L1, which involves engaging in practice activities to strengthen word recognition and spelling skills.

In the grammar-translation approach, the L1 plays a prominent role in building form-meaning links, especially in the initial phase of vocabulary learning (Nation,

2001). App tasks that incorporate the L1, such as L1–L2 translation and flashcards, intentionally support the establishment of these links (Schmitt, 2008). Translation offers the advantages of simplicity, speed and ease of understanding (Nation, 2001).

Input-based emergentism. ‘Emergentism’ is an umbrella term to define L2 learning as a state during which ‘learners use a general learning mechanism in order to extract structure and patterns from the language input they are exposed to’ (Mitchell et al., 2019, p. 129). Emergentism thus includes several theories, such as usage-based, frequency-based, cognitive grammar, connectionism and priming (MacWhinney, 2015), which all emphasise the salience and frequency of target features in L2 input (Mitchell et al., 2019). Through frequent encounters with these semantic and syntactic connections, learners develop a mechanism for prediction and generation (Lightbown & Spada, 2013). Psycholinguistic studies have provided evidence to support emergentism, showing that language processing is sensitive to usage frequency at all levels, including phonology, lexis, syntax and sentence processing (N. C. Ellis, 2002).

In vocabulary learning, the frequency of basic units, such as morphology, part of speech, and inflections, contributes significantly to learners’ exposure to the target vocabulary. Learners are attentive to the frequency of these inputs as they encounter and process them. Therefore, providing appropriate chunking and comprehensible inputs is crucial in emergentism for effective vocabulary learning.

Input-based pedagogies and VLS. Chunking, a prominent pedagogy in emergentism, was introduced by Miller (1956). It involves the process of grouping chunks (units of memory organisation) in short-term memory to form larger units in long-term memory (N. C. Ellis, 2003; Newell, 1990). Melton (1963) found that regularly repeated sequences in short-term memory become strongly embedded in long-term memory, forming what are perceived as chunks. Words are comprised of morphemes that exhibit sequential patterns. These patterns follow specific rules in word formation and etymology, such as compounding and derivation. Therefore, word sequences can be divided into meaningful chunks that emphasise the sequences’ salient features. For instance, the spelling tasks on vocabulary learning apps require learners to repeat and memorise a sequence of letters, making this a primary sequential chunking task.

By learning chunks and becoming more aware of their representative meanings, learners develop a statistical learning mechanism to predict meanings when encountering new words. MacWhinney (2001) highlights that language knowledge involves statistical knowledge, as learners fluently process regular patterns exemplified by abundant input, facilitating learning. By familiarising themselves with the rules and frequencies of word chunks, learners gradually deduce meanings of lexical items, thus expanding their mental lexicon. However, a potential hazard lies in overgeneralised rules leading to fossilised errors, which might become autonomous

habits without a teacher's instruction. Therefore, learners must simultaneously acquire vocabulary and grammatical rules.

Other input-based pedagogies aim to emphasise exposure to meaning-focused language, including the comprehensible input approach influenced by Krashen's (1985) affective filter hypothesis (Jamal, 2016). Vocabulary apps employ example sentences and L2 explanations and definitions to provide comprehensible input with a focus on meaning. Example sentences not only offer input but also exemplify authentic usage, allowing learners to discover patterns in word usages and assemble ready-made chunks for language production (Pavičić Takač, 2008). Unlike internal chunking within lexical items, example sentences create conventionalised and predictable longer language sequences, bringing learners closer to native and authentic word usages (Pavičić Takač, 2008).

L2 explanations/definitions are sometimes seen as definition-based learning, providing only one definition, synonym or translation of a word in the native language (Amirian & Momeni, 2012). However, vocabulary apps usually present the target language in a limited quantity, and L2 explanations and definitions offer more detailed insights by including additional syntax, grammar, semantics and collocations with other lexical items, increasing learners' exposure to the target language.

Yet, it is important to note that the input provided by example sentences and L2 explanations or definitions is limited in quantity due to the short length of the texts displayed on the screen. The word knowledge provided – such as phonological categories, collocations and lexical phrases – is thus also limited, resulting in minimal context and register.

Sociocultural theory (SCT). SCT, proposed by Vygotsky (1978), emphasises the social mediation of human development, whereby children acquire cultural values, beliefs and problem-solving techniques through cooperative conversations with more experienced members of society. Lantolf (2000) applied SCT to L2 learning, highlighting that the human mind is mediated. The mediation in L2 learning takes place through interaction with others (verbal and non-verbal), self-mediation through private speech and engagement with artefacts. In the context of MAVL, mediation primarily occurs through artefacts and social interactions, as these facilitate language learners' interactions with mobile devices and fellow online learners, enabling language learning outside the classroom (Ma, 2017).

SCT-based pedagogies and VLS. Vocabulary learning on apps can be mediated through imagery and semantic mediation, with the keyword method being a strategy that combines both approaches. This method involves three stages: semantics, orthography and imagery association. The keyword method addresses the vital concern of vocabulary retention and is based on the involvement-load hypothesis (ILH) in vocabulary learning. This hypothesis claims that the depth and width of lexical processing contribute to vocabulary acquisition (Hulstijn & Laufer, 2001).

Keyword method advocates argue that it is effective because it involves elaborate processing of visual, verbal and cognitive information (Crowston, 1993). However, the keyword method is limited in that it may only work for a small proportion of vocabulary items, and the associative links can make the retrieval of target words challenging. The keyword method can also be less effective for production compared to comprehension and reception, as the association between target words and keywords is temporary, requiring more procedural and productive knowledge (Hulstijn, 2001).

Previous MALL research has also discussed collaboration and connectivity with peers as a means of mediation in SCT (Kukulska-Hulme & Shield, 2008; Rosell-Aguilar & Qian, 2016). Collaboration is essential for tasks aimed at internalisation in SCT, achieved through group work and incentives (Zou et al., 2019). However, apps lack instruction, feedback and effective connectivity with other users (Burston, 2014; Godwin-Jones, 2011), and learners rarely negotiate meaning with others online (Kukulska-Hulme & Shield, 2008; Rosell-Aguilar & Qian, 2016). This issue prompts the need for further research on designing features that promote collaboration and feedback (Ludwig, 2018; Rosell-Aguilar & Qian, 2016).

Information/cognitive processing theories. Information/cognitive processing theories seek to explain learners' internal mechanisms through an investigation of how information is processed, transformed, stored and retrieved (Samuels & Kamil, 2002). Sub-theories include: CTML, DCT, and cognitive load theory (CLT) (Yang et al., 2021).

DCT proposes that human cognition operates with two distinct yet interconnected systems: an imagery system and a language system (Paivio, 1990). These systems allow for simultaneous processing of language and non-verbal objects and events. However, Singh and Solman (1990) proposed the blocking hypothesis, suggesting that compound stimuli (e.g. picture plus words) may hinder word automatisation due to prior familiarisation with picture-word associations.

Mayer's (2014) CTML aligns with Singh and Solman's (1990) blocking hypothesis, emphasising the limited information processing capacity in each channel described by DCT. According to Baddeley's (1986, 1999) theory of working memory and CLT (Sweller, 1999), learners can only hold a few images at a time in their working memories (Mayer, 2014). Therefore, supplementary materials may be needed for images to help learners identify key components of concepts or provide contextual information (Nation, 2001).

Information/cognitive processing pedagogies and VLS. The use of pictures or other visual aids is a frequently found technique embedded in visual learning pedagogy, which has been influenced by DCT and CTML (Raiyn, 2016). Visual learning is defined as 'the assimilation of information from visual formats' (Raiyn, 2016, p. 115). Using information such as actions, objects, pictures or diagrams and real objects, visual learning is one of the most reliable means of conveying the meaning of a word

(Nation, 2001). It assists students in better understanding and retaining information by associating ideas, words and concepts with images (Raiyn, 2016).

The use of images – wherein learners see visual representations of words' meanings – aids information storage and memory retrieval (Kasper, 1993). Pictures serve as mnemonic tools, triggering short-term memory and promoting deeper processing for extended retention (Hulstijn & Laufer, 2001). Flashcards, a well-established pictorial device, provide a visual instance of meaning, leading to prolonged retention (Nation, 1990). Apart from information/cognitive processing theories, picture-choice tasks may also be seen as a tool that mediates both the relationship between words and the learner and the relationship between short-term and long-term memory. The difference between picture choices and imagery mediation is that pictures function to directly convey meanings, while imagery mediation relies on associations, which require more elaborate processing by the brain.

2.5 Research questions

This study reviews the VLS, vocabulary pedagogies and language learning theories of four Chinese–English vocabulary learning apps that aim to achieve pedagogical optimisation. In so doing, it seeks to answer the following research questions (RQs):

- RQ1:** What types of tasks and VLS are incorporated into the selected English vocabulary learning apps?
- RQ2:** Which learning theories and pedagogical approaches inform the task design and VLS in the selected English vocabulary learning apps?
- RQ3:** In what ways can learning theories and pedagogical approaches inform and enhance the future development of English vocabulary learning apps?

3 Methodology

3.1 Selection process

This study employed purposive sampling to select four English vocabulary learning apps measured by a Chinese professional mobile data analysis platform, Qimai, launched by the Beijing Qimai Technology Company. Qimai offers statistics on all

Table 3: Four selected apps.

Application name	BaiCiZhan 	Bubei 	Momo 	Shanbay 
Launch date	25/09/2012	22/02/2014	13/07/2014	13/09/2013
Overall ranking	151	307	381	477
Ranking in education category (free download)	8	13	24	29
Ratings (max. 5)	4.8 (1,117,755 reviews)	4.9 (229,018 reviews)	4.9 (692,809 reviews)	4.7 (73,006 reviews)
In-app purchases	10 services	10 services	7 services	10 services

Note. Data retrieved from Qimai.cn on 15 November 2022.

apps on Google Play, the Apple’s Store and the nine largest Chinese Android markets; it also offers tools for keyword growth and app store optimisation (Fan et al., 2022). This platform has served as the data sampling tool in multiple studies pertaining to online education (e.g., Chen et al., 2021; Chen, Peng, Jing et al., 2020; Chen, Peng, Yin et al., 2020).

The study’s sampling criteria were based on the highest download rankings and the best review ratings of the English vocabulary apps in Qimai’s the Top 50 list of education category for free downloads. Four English vocabulary apps were found to feature in the Top 50 list in the education category (for free downloads) on Qimai: BaiCiZhan, Bubei, Momo and Shanbay. These apps were selected for investigation in this study (see details in Table 3). The rationale for selecting Chinese–English vocabulary apps is that Chinese EFL learners comprise a major portion of the vocabulary app market, and the vast array of apps available in China provides a rich dataset for sampling. It is important to highlight that the relevance of the four selected apps is not confined to the Chinese EFL context; instead, they are generalisable, since design aspects and tasks can be found in other vocabulary apps, such as Mindsnacks Spanish and Voxy (see Heil et al., 2016).

3.2 Coding procedures

The four apps were coded for the following variables: the vocabulary learning tasks they used, the VLS category in which each could be placed and the pedagogies and language learning theories on which they were based. Vocabulary learning tasks were coded in an open coding manner in compliance with Strauss and Corbin’s (1990) definition of open coding, with individual vocabulary learning tasks firstly identified and then grouped based on their properties. Subsequently, the codes for the VLS were determined with reference to Schmitt’s (1997) VLS taxonomy to develop a VLS

category for the selected apps. The pedagogies and theories were initially coded using the previous theoretical frameworks developed by Yang et al. (2021) and Jamal (2016). However, some of the pedagogy and theory codes were altered in a bottom-up manner by comparing the theories and pedagogies and seeking and justifying the interconnections and commonalities among them and with the vocabulary learning tasks found on the four apps.

4 Findings

4.1 Vocabulary tasks and VLS taxonomy

Table 4 shows the 23 vocabulary learning tasks found on the selected apps.

BaiCiZhan includes 18 tasks, Bubei 11 tasks, Momo 13 tasks and Shanbay 12 tasks. The six learning tasks that were found most frequently were L1–L2 paired translation,

Table 4: Vocabulary learning tasks on four apps.

	BaiCiZhan	Bubei	Momo	Shanbay
L1–L2 paired translations	✓	✓	✓	✓
Word articulations	✓	✓	✓	✓
Inflections and derivatives	✓	✓	✓	✓
Morphemes (roots + affixes)	✓	✓	✓	✓
Parts of speech	✓	✓	✓	✓
Example sentences with sounds	✓	✓	✓	✓
Collocations		✓	✓	✓
Bilingual dictionaries		✓	✓	✓
Listening practice/dictation	✓	✓		✓
Keyword method	✓		✓	✓
Note taking		✓	✓	✓
Note sharing			✓	✓
Spelling out loud	✓		✓	
Spelling checks by typing letter by letter		✓	✓	
Gamification	✓			
Fill in the blanks using letters/chunks	✓			
Pictographic associations	✓			
Instructor explanation	✓			
Online streak programmes	✓			
Mini lectures	✓			
Picture choices	✓			
Explanations/definitions in English	✓			
Learning groups	✓			

word articulations, inflections and derivatives, morphemes, parts of speech and example sentences with sounds. There were nine tasks which found less frequently, only on BaiCiZhan: gamification, fill in the blanks using letters or chunks, pictographic associations, instructor explanation, online streak programmes, mini lectures, picture-choices, explanations/definitions in English and learning groups.

Table 5 presents 23 vocabulary learning tasks found on the four apps. They were categorised into five VLS groups based on Schmitt’s taxonomy.

Fifteen of these were assigned to two VLS categories as they were found to have dual functions. Word articulation is the only task that was determined to belong to three categories.

Discovery strategies. On the four selected apps, discovery strategies were found to inform the tasks embedded in new word learning, when learners first encounter words. The DET identified differed from those proposed in Schmitt’s taxonomy, and SOC were absent given the absence of teachers. Eleven learning tasks were found to be driven by DET: L1–L2 paired translation, part of speech, morphemes, inflections and

Table 5: VLS taxonomy and vocabulary tasks.

VLS	Vocabulary tasks on four apps
DET	Parts of speech
DET	Bilingual dictionaries
DET/MEM	L1–L2 paired translations
DET/MEM	Example sentences with sounds
DET/MEM	Keyword method
DET/MEM	Picture choices
DET/MEM	Explanations/definitions in English
DET/MEM	Inflections and derivatives
DET/MEM	Morphemes (roots + affixes)
DET/MEM	Pictographic associations
DET/MEM	Collocations
DET/MEM/COG	Word articulations
MEM/COG	Listening practice/dictation
MEM/COG	Gamification
MET/COG	Spelling checks by typing letter by letter
MET/COG	Fill in the blanks using letters/chunks
MET/COG	Spelling out loud
COG	Note taking
SOC	Note sharing
SOC	Instructor explanation
SOC	Online streak programmes
SOC	Mini lectures
SOC	Learning groups

derivatives, word articulations, picture-choices, pictographic associations, keyword method, bilingual dictionaries, example sentences with sounds and explanations/definitions in English.

Schmitt (1997) asserted that DET offer learners four options for understanding new vocabulary: guessing from structural knowledge of the target language, relying on the L1 cognate and context, using reference materials or asking someone else. Structural knowledge may include word parts, such as morphemes, inflections and derivatives. Learners may also be able to discover meaning by discerning a word's part of speech (Schmitt, 1997). The option to guess from the L1 cognate was not provided on the four apps as there are very few phonological cognates (words that share visual, phonological and semantic similarity between languages) and no orthographical cognates between Chinese and English (Yang et al., 2017). Instead, the four apps presented L1–L2 paired translations to convey word meaning explicitly. Guessing from context usually requires various sources besides written texts, such as pictures, intonations in a spoken discourse (Schmitt, 1997) and picture choices. The keyword method and pictographic associations that use pictures to convey meaning accord with such a description of guessing from context. Regarding finding a word's meaning through reference materials, the use of bilingual dictionaries is a primary exemplar. On top of these four options, example sentences with sounds also help learners guess meaning contextually. Other DET found on the apps, such as the collocations and explanations/definitions in English provided by BaiCiZhan, are conducive to constructing meaning for new words and do not necessarily require guessing from context. Asking someone else, which belongs to the SOC category, was not found on any of the four apps.

Consolidation strategies. There were four categories of VLS on the four apps for the consolidation and revision of new vocabulary words: SOC, MEM, COG and MET. SOC include instructor explanations, online streak programmes, mini lectures and learning groups that combine the role of virtual teachers with that of peers. MEM involve several DET because they reoccur in revision tasks on the four apps to consolidate word meaning and facilitate recall. Such tasks include L1–L2 paired translations, word articulations, inflections and derivatives, morphemes, example sentences with sounds, the keyword method, picture choices and explanations/definitions in English. MEM also include word articulations, collocations, listening practice and dictation and gamification. COG, which focus on written or verbal repetition and the use of mechanical means to study knowledge about a word include listening practice and dictation, spelling out loud, word articulations, gamification, note taking, spelling checks and fill in the blanks. Spelling-related tasks and fill in the blanks have dual functions in MET because they also help learners to monitor and evaluate learning progress.

4.2 Vocabulary pedagogies and theories

Table 6 categorises the 23 tasks found on the apps into four language learning theories and their corresponding pedagogies, as previously described in the literature review. L1–L2 paired translations and bilingual dictionaries correspond to the grammar-translation approach. Word articulation and listening practice and dictation correspond to the audio-lingual approach. Both pedagogical approaches are influenced by behaviourism.

Table 6: Theoretical and pedagogical synthesis table for vocabulary learning apps.

Theory	Pedagogy	VLS	Vocabulary tasks on apps	App
Behaviourism	Grammar-translation approach	DET/MEM	L1–L2 paired translations	BaiCiZhan Bubei Momo Shanbay
		DET	Bilingual dictionaries	Bubei Momo Shanbay
		MEM/COG	Listening practice/dictation	BaiCiZhan Bubei Momo Shanbay
				BaiCiZhan Bubei Momo Shanbay
	Audio-lingual approach	DET/MEM/COG	Word articulation	BaiCiZhan Bubei Momo Shanbay
		DET/MEM	Morphemes (roots + affixes)	BaiCiZhan Bubei Momo Shanbay
				BaiCiZhan Bubei Momo Shanbay
				BaiCiZhan Bubei Momo Shanbay
Input-based emergentism	Chunking	DET	Parts of speech	BaiCiZhan Bubei Momo Shanbay
		DET/MEM	Collocations	Bubei Momo Shanbay
		DET/MEM	Inflections and derivatives	BaiCiZhan Bubei Momo Shanbay
		MET/COG	Fill in the blanks using chunks/letters	BaiCiZhan

Table 6: (continued)

Theory	Pedagogy	VLS	Vocabulary tasks on apps	App
Sociocultural theory	Comprehensible input	MET/COG	Spelling checks by typing letter by letter	Bubei Momo
		MET/COG	Spelling out loud	BaiCiZhan
		DET/MEM	Example sentences with sounds	BaiCiZhan
		DET/MEM	Explanations/definitions in English	BaiCiZhan Bubei Momo Shanbay
	Imagery and semantic mediation	DET/MEM	Keyword method	BaiCiZhan Momo Shanbay
		DET/MEM	Pictographic associations	BaiCiZhan
		SOC	Learning groups	BaiCiZhan
			Note sharing	Momo Shanbay
			Gamification	BaiCiZhan
		SOC	Mini lectures	BaiCiZhan
		SOC	Online streak programmes	BaiCiZhan
		SOC	Instructor explanation	BaiCiZhan
		COG	Note taking	Bubei Momo Shanbay
	Visual learning	DET/MEM	Picture choices	BaiCiZhan

Input-based emergentism encompasses two major pedagogies, namely chunking and comprehensible input. The chunking pedagogy informs the use of morphemes (roots + affixes), parts of speech, collocations, inflections and derivatives, fill in the blanks and spelling-related tasks. Comprehensible input informs two tasks: example sentences with sounds and explanations/definitions in English.

SCT inspires two pedagogies and seven tasks. The keyword method and pictographic associations are part of imagery and semantic mediation pedagogy. Learning groups, gamification, mini lectures, online streak programmes, instructor explanation, note taking and note sharing are collaborative and interactive activities.

Information/cognitive processing theories mainly engage visual learning pedagogy. This is used to inform picture-choice tasks on BaiCiZhan.

Table 7: Differences between Schmitt’s VLS taxonomy and tasks and VLS found on selected four apps.

Stage of vocabulary acquisition	VLS category	VLS	Schmitt’s VLS taxonomy	Four selected apps
Discovery stage	SOC	Asking someone else	✓	×
	DET	Guessing from L1 cognates	✓	×
		Word articulations; keyword method; pictographic associations	×*	✓
Consolidation stage	COG	Note-taking	×*	✓
	SOC	Online streak programme; note sharing; mini lectures	×	✓
		Gamification	×	✓
		L1–L2 paired translations; inflections and derivatives; morphemes; example sentences with sounds; picture choices; explanations or definitions in English	×*	✓
	MET	Use L2 media; skip or pass over new words	✓	×

Note. *means it is only found in the other stage.

Table 7 presents the differences found between Schmitt’s VLS taxonomy and tasks and the VLS found on the four selected apps, by stage of vocabulary acquisition.

As shown in Table 7, at the discovery stage the most noticeable difference between Schmitt’s VLS taxonomy and the VLS employed in the four selected apps was that the apps lacked SOC and guessing from L1 cognates (as Chinese and English belong to two different language families and thus share very few cognates) but integrated word articulations, the keyword method and pictographic associations.

At the consolidation stage, several VLS found in the apps were not included in Schmitt’s taxonomy: SOC, which include online streak programme, note sharing and mini lectures, and MEM/COG, which include gamification. This is because Schmitt’s taxonomy was created before the existence of gamification. There was also a reoccurrence of six DET that are used as MEM, including L1–L2 paired translations, inflections and derivatives, morphemes, example sentences with sounds, picture choices and explanations or definitions in English. In addition, two strategies in Schmitt’s MET category – use of English media and skipping new words – were not found on the selected apps.

BaiCiZhan offered the widest array of SOC strategies from SCT at the consolidation stage among the apps. It was the only app that provided vocabulary games and recorded instruction to promote mediation between peers and experts. It was also the only app that had mini lectures to answer frequently asked questions, which, to a

certain extent, fulfils the role of an instructor. However, during one of the app's games, the 'vocabulary duel', learners rarely received the opportunity for simultaneous communication with others. Rather, this game focused intrinsically on strengthening the connection between form and meaning by encouraging retrieval from memory.

5 Discussion

5.1 VLS taxonomy on four apps

It was observed in the findings that there are differences between Schmitt's VLS taxonomy and the way the categories of this taxonomy have been applied to the four selected apps. First, the exclusion of SOC can be attributed to the vocabulary apps' lack of teachers or peers who could provide immediate instruction on new words. This can also be attributed to the informal nature of the MAVL context, where learners predominantly engage in self-directed learning without external or interpersonal support. While SOC is also included in other VLS taxonomies, such as Oxford's (1990) and O'Malley and Chamot's (1990), the necessity of SOC in the discovery stage requires further investigation within MAVL.

During the consolidation stage, the recurrence of DET and MEM through review tasks serves a twofold aim: It promotes the repetition and retrieval of word knowledge (O'Malley et al., 1985) and follows the trajectory of scaffolding described in SCT. When facilitative hints disappear in revision, and learners need to recall the meaning of a word, retrieval is triggered. Word retrieval is essential to retention because a delayed presentation of a word's form and meaning requires greater effort, which might cause longer and stronger retained learning (Nation, 2001). Retrieval also demands deeper processing and recall since the forms and meanings of words are presented separately. Meanwhile, the withdrawal of facilitative hints resembles 'scaffolding', which is defined as 'a process of setting up the situation to make the child's entry easy and successful and then gradually pulling back and handing the role to the child as he becomes skilled enough to manage it' (Bruner, 1983, p. 60). In the MAVL context, scaffolding is facilitated not by peers or instructors but rather through an app's algorithm and the design generated from a user's usage database.

In addition, the inclusion of four MEM/COG at the discovery phase attests that due to the multimodality of the selected apps, the boundary between discovery and consolidation strategies is blurred as different types of strategies are presented on the same screen. Consequently, learners engage with a wide range of new word knowledge, not only a word's form and meaning but also its use, and their retention is simultaneously enhanced by the use of multiple VLS at the discovery stage. The apps' multimodality also provides opportunities for more intellectual SOC and MEM/COG, as shown in Table 7.

5.2 Evaluation of four apps

Strengths. At the discovery stage, L1–L2 paired translation is the most common task, designed to build effective form-meaning links. Parts of speech, inflections and derivatives, morphemes, example sentences with sounds and articulations are also included by all four apps, reflecting the theoretical integration of input-based emergentism, enhancing lexical and grammatical knowledge within an authentic language usage context.

At the consolidation stage, BaiCiZhan, Bubei and Momo utilise spelling exercises to help learners self-evaluate retention accuracy. On Bubei, Shanbay and Momo, learners can take notes to facilitate their internalisation of word knowledge. Taking notes can be seen as a means to mediate between previous knowledge and new words. Through the note-sharing function on Shanbay and Momo, users can share information about morphemes, derivatives and inflections. In this way, the way in which lexical knowledge is acquired using chunks varies, and users are endowed with more mnemonic techniques.

In terms of interaction and collaboration, BaiCiZhan not only creates an interactive environment where users can communicate and negotiate knowledge through group-learning, but it also includes tasks that aim to fulfil the role of ‘instructors’ through continually updated mini lectures and instructor explanation.

Weaknesses. First, one concern about L1–L2 paired translation is that translation from the L1 sometimes loses the nuances of a word’s diverse meanings, and EFL learners tend to memorise the most basic and frequent core meanings above all others (Carter & McCarthy, 1988). Another concern relates to the semantic equivalent hypothesis (Ijaz, 1986), which holds that relabelling concepts in the L2 that have already been learned in the L1 ignores cross-lingual differences in conceptual categorisation and semantic boundary differences in paired translations.

The value of using pictures on BaiCiZhan as a form of visual learning is also contested. The main disadvantage is that pictures, as a means of transforming ideas into an observable image, might be misinterpreted by learners and fail to communicate the concept of the target word as a visual form. Moreover, not all words can be conveyed pictorially (Nation, 2001).

Regarding interaction and collaboration, Bubei, Momo and Shanbay still have limited utilisation of mobile features to create online connectivity that allows learners to construct and negotiate word knowledge with others. Mediation by other users in social interactions is realised on Momo and Shanbay only through note-sharing tasks. By comparison, BaiCiZhan and Bubei do not embed a note-sharing function to enable learners to access other users’ notes on collocations and other associative word knowledge. This results in a limited comprehensive lexical knowledge and a relatively isolated online learning environment.

Furthermore, the tasks and VLS on the four apps seldom help develop productive word knowledge (i.e., through speaking and writing) to communicate and convey meaning. The designs of revision tasks on the four apps emphasise elaborative repetition that is believed to be more conducive to retained memory (Nation, 2001). However, the four apps seldom complement such revision exercises by challenging learners' knowledge of a word's use or allowing them to use lexical items in a freer manner. There is also little opportunity for learners to become engaged in an authentic context in which they can reencounter or use new lexical items. This is attested by the absence of the use of English media. Thus, learners are likely to acquire both productive and receptive knowledge in a less effective manner.

5.3 Prospects for vocabulary learning apps

Cognitive and psychological inspiration. It is essential to revisit O'Malley and Chamot's (1990) tripartite cognitive VLS model, which was mentioned in the literature review. Their model illustrates the transfer processes between declarative and procedural knowledge. Declarative knowledge refers to static factual knowledge, representing what learners know about a domain, while procedural knowledge involves the ability to comprehend and apply language rules to problem-solving without conscious effort (Kudo, 1999). These three-stage transfers align with Nation's (2001) steps of vocabulary acquisition, noticing, retrieval and generation, which form a continuum. The four selected apps are effective in the first two stages, but further development is needed to address the last stage of autonomous-generation.

The initial cognitive-noticing stage involves learners knowing a fact about a lexical item, such as its phonological and morphosyntactic features, or building a form-meaning link but struggling to produce it correctly in a sentence (R. Ellis, 2008). Although the four selected apps effectively provide declarative knowledge through explicit vocabulary learning tasks, such as L1–L2 paired translations and L2 definitions, more explanations of a word's meaning and instances of its usage should be provided to avoid learners gaining an insufficient sense of its meaning, particularly if there are no equivalent words in translation. Meanwhile, the noticing can occur on apps when users pay attention to example sentences and recognise word collocations and semantics instead of noticing a single word as a meaningful language item.

In the associative-retrieval stage, frequency plays a vital role. Learners attempt to group information into efficient production sets by collapsing discrete productions and applying general rules to specific instances (R. Ellis, 2008). The four apps support this process by synthesising chunks of language through morphemes, collocations, derivatives and fill-in-the-blank tasks, encouraging users to discover, generalise and apply lexical rules for vocabulary learning and memorisation. The emphasis on retrieval involves

increasing the frequency of encounters with previously learned words, which is achieved through the apps' revision tasks. These tasks can be more productive in nature, allowing learners to communicate a word's meaning orally or in writing.

However, the four apps lack substantial evidence of their ability to foster generative use or automatised use. Generative use refers to encountering words in different contexts, leading learners to re-evaluate their understanding of a word (Nation, 2001). This process facilitates mental elaboration, enriching the word's processing level (Baddeley, 1990) in alignment with the Involvement Load Hypothesis. Consequently, learners can make generalisations and use the target word more effectively. Although BaiCiZhan's imagery mediation and picture-choices demand elaborate processing, they do not require learners to reconceptualise their prior knowledge of target words in a new context. The tasks provided by the apps are often decontextualised and lack engagement and opportunities for production. In contrast, vocabulary apps should include language practice that facilitate actual target behaviours in authentic contexts, such as conversing with peers, writing for practice, watching original series, reading English novels and engaging in other ways with English-language media. Such practice is beneficial for proceduralisation and automatised use.

SLA theoretical inspiration. From the perspective of SLA theory, pedagogies and VLS influenced by Swain's (1985) output hypothesis (OH) can be integrated into the design of apps to create generative-use tasks. Swain (1985) argued that learners need to produce output to fully master their L2. Although Swain emphasises dialogic communication, the production advocated by the OH can still be seen as a means to practice new words' forms, meanings and uses, thereby enhancing both receptive and productive knowledge. Potential tasks and VLS can include sentence-making, synchronic conversation with peers or instructors online and other SOC/COG and tasks that aim to produce vocabulary knowledge. During the output process, learners are meanwhile required to engage in thorough grammatical processing, advancing the development of L2 syntax and morphology in the most efficient way (Swain, 1985).

Furthermore, Swain (1985) highlighted that during the output process, students are conscious of their L2 limitations and can reflect on them. Since it is hard for individual learners to achieve meta-cognition, vocabulary apps need to integrate corrective feedback functions to help users reflect on and correct mistakes. The primary issue encountered by college students in China when using such apps is the absence of effective communication and feedback, as highlighted by Hu et al. (2023). A facilitator who can discuss and analyse mistakes explicitly and promptly is necessary on vocabulary apps, and such a figure could serve as an automatic correction system. In such an informal and mobile learning context, metalinguistic interaction can also take place between peers through online interaction tasks, such as in group meetings, short message services and multimedia message services (Lin & Lin, 2019). Such tasks and VLS can possibly contribute to lexical development while providing opportunities to experiment with different structures and forms of words (Swain & Lapkin, 1998).

In addition to OH, input-based pedagogies can be optimised on the selected apps. While most apps rely on example sentences accompanied by sound and L2 definitions, Krashen (1985) claimed that the most efficient way to learn vocabulary is through exposure via extensive reading. However, contextualised reading tasks should be provided to intermediate-level learners who have reached a threshold for vocabulary size (Laufer, 2003). It is important to note that the context approach cannot be applied on its own. To meet this threshold requirement, the app's algorithm must accurately capture learners' vocabulary proficiency and select appropriate reading materials that are just beyond their current level while also including previously encountered words.

In addition to providing extensive reading texts, vocabulary apps can utilise multimedia input-based tasks and MEM/COG that engage English-language media, such as videos, audio and picture books (Guo & Li, 2022; Wang et al., 2021). However, it is worth noting that due to the limited capacity mentioned in CTML (Mayer, 2014) and CLT (Sweller, 1999), the number and design of other types of multimedia input should be carefully planned by app designers to avoid mental overload (Wang et al., 2021).

6 Conclusions

This study has undertaken a theory-driven review of the vocabulary learning tasks, VLS, pedagogies and theories that are found on vocabulary apps designed for Chinese learners of English. The results indicate that apps provide multiple tasks that can be individualised for language learners to meet their vocabulary needs. However, they also reveal that vocabulary learning tasks need to provide more collaboration and authentic output opportunities. However, the four apps selected were found to neglect the acquisition of procedural knowledge and the generative use of lexical items. Due to its incremental nature, the vocabulary learning process proposed by Nation (2001) – noticing, retrieving and generating – connects individual VLS, pedagogies and theories as they inform the dynamic process of vocabulary development over time. Accordingly, pedagogies and tasks will change at different stages, to meet not only the needs of learners at different proficiency levels but also the needs of learners' development over time.

However, the study has certain limitations. First, it only focuses on vocabulary learning apps in the Chinese market, while there is a need for a more comprehensive analysis of commercial vocabulary learning apps globally. Moreover, the study only included four apps from Qimai's Top 50 list, excluding vocabulary learning apps that were not listed in the Top 50. Second, the study has not assessed the effectiveness of the

apps, leaving open the question of which app and which design are more conducive to enhancing students' vocabulary learning. Future empirical investigations may therefore attempt to illuminate the usefulness of different vocabulary apps. Lastly, the issue of how learners can achieve metacognition through collaboration and connectivity on apps remains unresolved. Further investigation is needed to determine the extent to which these activities contribute to knowledge internalisation and procedural knowledge.

Informed consent: The data was retrieved from an open platform and mobile applications that allow research for non-commercial purposes under the regulation of CC BY-NC-SA 4.0 DEED.

Ethical approval: Ethical approval was sought and approved by the Faculty of Education, University of Cambridge under the regulation of the government of the UK.

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