Effects of Mode of Target Task Selection on Learning About Plants in a Mobile Learning Environment: Effortful Manual Selection Versus Effortless QR-Code Selection

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This study compared the effects of effortless selection of target plants using quick respond (QR) code technology to effortful manual search and selection of target plants on learning about plants in a mobile device supported learning environment. In addition, it was investigated whether the effectiveness of the 2 selection methods was differentially affected by the number of target plants (6, 8, 10 plants) the students could choose from. Results on a plant recognition test revealed that selection through QR codes was superior to manual selection when the number of plants was high, whereas manual selection was superior with the lower and medium number of plants. In contrast, results on a leaf morphology test revealed that the QR code technology was more effective compared to the manual search selection for learning regardless of the number of target plants. The theoretical and practical implications of the results are discussed.

**Keywords:** quick response code, cognitive load, working memory capacity, working memory resources, mobile learning, subsequent-task effect

A growing number of technological devices that are utilized within the educational context are produced in portable form (e.g., iPods, smartphones). The learning by means of handheld wireless technological devices, which is independent of time and location, is called mobile learning (Attewell & Savill-Smith, 2005; Ruchter, Klar, & Geiger, 2010). Despite the high level of popularity of mobile technology in education, its use is not without constraints and limitations. A fundamental obstacle to the effective use of educational technology is the lack of the appropriate, specific guidelines and principles. This lack of guidelines and principles carries the risk of thoughtless and improper application of technology in learning, which becomes evident from the contradictory results regarding the effectiveness of technology-based learning environments (e.g., for positive effects, Chen & Levinson, 2006; Klar, Geiger, 2005; for negative effects, Chen, Teng, Lee, & Kinshuk, 2011; Darabi, Nelson, & Palanki, 2007; Scheiter, Gerjets, Huk, Imhof, & Kammerer, 2009). Many technological advances seem to be ahead of our understanding of how students learn from new learning technologies. To increase our understanding it is important to investigate the conditions under which students learn effectively with learning technologies. In this study we tried to determine these conditions for a mobile learning environment based on quick response (QR) codes.

QR codes are a type of two-dimensional matrix barcode that can be encoded by mobile devices equipped with built-in cameras and the appropriate QR code-reading software at a high speed. By scanning the image of QR codes with the camera of mobile devices, users are able to gain instant access to a variety of information stored in the QR codes, including textual information and standard URLs (Uniform Resource Locators) for websites. The potential use of the QR code technology in education has been addressed in several recent studies (e.g., Ozcelik & Acarturk, 2011; Uluyol & Agca, 2012), most of which supported that the QR code technology could be used as a new approach to reinforce effects of printed materials in a classroom. In addition, QR codes were also found to be effective in libraries and museums (e.g., Hampton, Peach, & Rawlins, 2012; Massis, 2011; Schultz, 2013). In line with the contradictory results generally found regarding the effectiveness of technology-based learning environments, several studies on the use of QR codes have failed to find positive effects (e.g., Chen, Teng, Lee, & Kinshuk, 2011).

Previous research indicates that learning with the support of QR code technology typically consists of two stages: (a) recognize (correct selection of the learning target on an electronic device) and simultaneously access the stored information, and (b) learn about the stored information. Most studies have focused on the
learning performance at the second stage, investigating whether simplifying the recognition by using QR codes could facilitate the acquisition of information. However, no study has yet explored whether using QR codes is also effective for the recognition process, and how the initial recognition of information by means of QR code technology affects the quantity and quality of subsequent information acquisition. The present study aimed to investigate the effects of QR codes on information recognition and acquisition in the context of plant learning by considering cognitive load.

A Cognitive Load Perspective

Cognitive load theory uses the characteristics of human cognitive architecture to investigate and design instructional procedures for better learning and problem solving (Kalyuga, 2009; Paas, Renkl, & Sweller, 2003; Sweller, 2003, 2010b, 2011, 2012; Sweller, Ayres, & Kalyuga, 2011; Sweller, van Merriënboer, & Paas, 1998). Focusing on processing limitations of the human cognitive system, the theory assumes a limited working memory and an effectively unlimited long-term memory (Sweller, 2003, 2004). Effective learning occurs only when cognitive load is controlled within the capacity limits of working memory. Recent cognitive load theory makes a distinction between the two independent sources of cognitive load. Extraneous cognitive load is caused by inappropriate instructional materials or procedures irrelevant to learning and so can be eliminated by optimizing instructional design without altering what is learned (see Sweller 2010a; Sweller et al., 2011 for a range of instructional techniques designed to reduce extraneous cognitive load). In contrast, intrinsic cognitive load is caused by the difficulty essential to learning and so cannot be reduced without altering the nature of learning materials (Sweller, 1994).

In the context of cognitive load theory, QR codes can be argued to serve as an offloading mechanism to reduce working memory load, because the computer, instead of the learner, searches and selects the relevant information to be learned. When searching and selection processes are executed automatically with QR code technology, the learner can use all available working memory resources for other processes. In contrast, without QR code technology, a substantial amount of working memory resources is consumed by manual searching and selecting activities. Consequently, fewer resources are available for other processes. In conclusion, QR code technology can be used to reduce extraneous cognitive load imposed by unnecessary initial manual search and selection of the information to be learned. However, if the learning aim is recognition, the cognitive load associated with manual search and selection will become essential and intrinsic for learning. Available working memory resources are used to repeatedly compare and contrast the learning targets by manual searching and selecting activities, facilitating the construction of relevant schemas for later use. In that case, the use of the QR code technology, by contrast, omits the cognitive processing essential to the learning aim of recognition, limiting the construction of schemas and hindering the learning. In addition, cognitive load theory suggests that all learning must be handled within the limits of working memory capacity (Sweller, 1994, 2003, 2010b). If the number of the targets to be searched or selected is increased beyond the point where the information can be processed, it might be a good way to use the offloading QR code technology, whether the task is learning to recognize or other activities because otherwise the working memory will overload in either case.

Overview of the Present Study

The purpose of the present study was to compare the effects of effortless selection of target plants using QR code technology to effortful manual search and selection of target plants on learning to recognize plants and acquiring plant leaf morphology knowledge in a mobile device supported learning environment. In addition, it was investigated how the differences between the two selection methods are affected by the number of target plants that the students could choose from. Specifically, two research questions were proposed in this study: (a) whether effortless computer-based selection of target plants through the use of QR codes can facilitate learning to recognize plants and acquiring knowledge of leaf morphology more than effortful manual search and selection of target plants, and (b) how this effect is mediated by the number of the target plants to select from and to be studied. A between-subjects factorial experiment design was used to explore the research questions, “selection conditions” and “number of target plants” being the between-subjects factors. In this study students could get access to the information related to the leaf morphology of a specific plant either by manually selecting the plant from a subset of plants presented on the mobile device (Manual search selection condition), or by scanning QR code attached to the real plant using the built-in camera of the mobile device (QR code selection condition). Plants had to be selected from subsets of either, 6, 8, or 10 plants for both selection conditions. The number of the target plants was started from six because all subtypes of leaf morphology need to be presented by at least six plants. A plant recognition test and a leaf morphology knowledge test were used to measure the differences of learning performance between the manual search and the QR code selection condition after acquisition phase.

In the present study, effortful manual selection of plants was assumed to contribute to the ability to recognize the plants because the students are confronted with a variety of examples. Selecting from a range of examples with different surface features has been shown to help learners focus on structural features (for an overview see, Guo, Pang, Yang, & Ding, 2012), which promotes construction of structure-based cognitive schemas, and development of more accurate understanding of the concept (e.g., Hammer, Bar-Hillel, Hertz, Weinshall, & Hochstein, 2008) or procedure (e.g., Paas & van Merriënboer, 1994). As long as the selection process does not overload the learner’s working memory capacity, effortful manual selection of plants will be superior to effortless selection based on QR code technology. By contrast, in case of selection by QR code technology, the learner cannot learn from the selection process, but only learn about the automatically selected examples. As soon as the selection process in the manual selection condition overburdens the learner’s working memory capacity, the selection process will fail and negatively affect the acquisition of recognition skill and plant leaf morphology knowledge. In that case, effortless selection using a QR code technique can become more effective for learning than manual selection. In subsequent acquisition of leaf morphology knowledge, however, QR code technology could prevent the cognitive load associated with manually searching that was unnecessary and extraneous for
leaf morphology acquisition and become more beneficial for learning no matter how many target plants need to be learned. Therefore, by considering these issues within a cognitive load theory framework, we hypothesized that the effects of using QR code technology on learning to recognize plants and acquiring leaf morphology knowledge might interact with using manual search and selection due to the increasing number of the target plants.

Two main hypotheses were generated: (a) For the plant recognition test, manual search condition might perform better (i.e., higher test scores and lower cognitive load) than QR code condition when learning a small number of the plants (6, 8 plants), and such advantages might disappear and even reverse when the number of target plants is high (10 plants). This hypothesis was made based on a general agreement that only seven plus or minus two elements of knowledge from the learning materials and the relevant learning tasks: (a) plant recognition: the students are able to recognize the target plants from a number of plants; (b) leaf morphology knowledge: the students are able to comprehend three main characteristics of plant leaves including venation, margin, and phyllotaxy, as well as four subtypes of venations (parallel-veined, feather-veined, palmate-veined, and midrib distinct), four subtypes of margin (entire, dentate, palmately lobed, and sinuate), and five subtypes of phyllotaxy (alternate, decussate, dichotious, whorled, and rosulate).

The learning materials were divided into four parts, Part 1 being presented to the participants on a laptop and Parts 2–4 being presented with a mobile device. First, Part 1 consisted of six screens presenting the learning materials including a welcome page and introduction about three main characteristics of leaf morphology as well as their subtypes, being identical for all conditions. Second, the following two screens were condition specific, in such a way that the students in the manual search condition was instructed to access to the relevant leaf morphology information for each plant by clicking the correct picture corresponding to the real target plant that they were watching, whereas the students in the QR code condition were instructed to get the access to the relevant leaf morphology information by scanning the QR codes on the real plants with the built-in camera of their mobile devices. Third, the following screens with text as well as pictorial instructions in each screen presented the leaf morphology knowledge for the target plants, four screens each plant, with the first screen presenting the plant with names and the other three screens presenting margin, venations, and phyllotaxy, respectively. The learning materials used in this part were identical for the manual search and QR code conditions, but differed as a function of the size of the selection subset, with 24 screens in the conditions with six plants, 32 screens (the 24 screens for the conditions with six plants included) in the conditions with eight plants, and 40 screens (the 32 screens for the conditions with 8 plants included) in the conditions with 10 plants. Before presenting the four screens of leaf morphology information for each plant, an additional screen displaying all pictures of target plants (6, 8, or 10) was first presented to the manual search condition for plant recognition. However, the same additional screens in the QR code condition were only a textual reminder to scan the QR codes. Finally, the last screen was the same in each condition, and was used to thank the students for their participation.

The experimental procedures involved three phases (see Table 1), which were executed over 2 days with an interval of 1–2 weeks. The experiment lasted 5 minutes on the first day for Phase 1 and approximately 45 minutes on the second day for Phases 2 and 3. The three phases were: (1) preacquisition phase (5 minutes on the first day), (2) acquisition phase (11–22 minutes on the second day, the fewest time being for the QR code condition with six plants and the most time being for the Manual search condition with 10 plants during this phase), and (3) a test phase (15 minutes on the second day).

Preacquisition phase. A pretest was conducted to investigate the students’ prior knowledge about leaf morphology. The students were required to finish 10 multiple choice questions in 5 minutes, with four alternative answers to each question. The answer sheets were collected at the end of the prior knowledge test. During the whole procedure of Phase 1, the students were not allowed to

Participants
A total of 190 fifth and sixth grade elementary school students from northern Taiwan (87 males and 103 females) volunteered to participate in the current study. The age range of the participants was 10 to 12 years. All participants followed the same curriculum at school. They were randomly assigned to six conditions, which differed regarding the selection of target plants (manually vs. QR code) and the size of the selection subset (6 vs. 8 vs. 10). Four participants (all females) did not complete the whole experiment and therefore were eliminated from the following data analyses and reporting.

Materials and Procedure
The experiment was conducted at two periods of class time with an interval of 1–2 weeks. The first period, which was used for the preacquisition phase of the experiment, took place in a normal natural science classroom. The second period, which was used for the acquisition and test phases, took place in the outdoor environment. In this period, all students were equipped with the same mobile devices and completed the learning and tests individually. For each student, the learning and test period was completed within a regular class time. This period lasted 2 weeks to complete for all the participants due to individual operation. Consequently, the amount of time separating the preacquisition phase and the learning and test phases could be up to 2 weeks. The materials and procedure for the two selection conditions were identical, except for the way to get access to the learning materials.

The materials used in this study were compiled by an experienced natural science teacher based on the national syllabus requirements. The materials that were used in this study were modifed from the materials used in previous studies of Liu, Lin, Tsai, and Paas (2012) and Liu, Lin, and Paas (2013). Modifications were based on the results of a pilot study, conducted 1 week before the start of the experiment, and performed by the same teacher and the authors. In general, the students were required to learn two levels of knowledge from the learning materials and the relevant learning tasks: (a) plant recognition: the students are able to recognize the target plants from a number of plants; (b) leaf morphology knowledge: the students are able to comprehend three main characteristics of plant leaves including venation, margin, and phyllotaxy, as well as four subtypes of venations (parallel-veined, feather-veined, palmate-veined, and midrib distinct), four subtypes of margin (entire, dentate, palmately lobed, and sinuate), and five subtypes of phyllotaxy (alternate, decussate, dichotious, whorled, and rosulate).
Table 1

Procedure of the Study for the Manual Search and Quick Response (QR) Code Selection Conditions as a Function of the Number of Plants

<table>
<thead>
<tr>
<th>Phase condition</th>
<th>Phase 1: Preacquisition</th>
<th>Phase 2: Acquisition (on the second day)</th>
<th>Phase 3: Test (on the second day)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Test 1. Recognizing test:</td>
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<tr>
<td></td>
<td></td>
<td>Multiple choice questions (6 items)</td>
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<tr>
<td></td>
<td></td>
<td>Manually search for the pictures that correspond to the real plants</td>
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<tr>
<td></td>
<td></td>
<td>Rate cognitive load questions (10 items)</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Learning time recording</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stage 2. Information acquisition</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Scan the QR code using the mobile devices</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cognitive load ratings</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Learning time recording</td>
<td></td>
</tr>
<tr>
<td>1: Manual search condition</td>
<td>Access to the stored information by manually search and selection</td>
<td>Learn the stored information about leaf morphology</td>
<td></td>
</tr>
<tr>
<td>2: QR code condition</td>
<td>Access to the stored information using QR code selection</td>
<td>Learn the stored information about leaf morphology</td>
<td></td>
</tr>
</tbody>
</table>

At the beginning of the acquisition phase, the students were assigned a Tablet PC with 10-inch monitor without keyboard and were asked to use this mobile device to learn about plants. The plants were randomly arranged in three rows with partitions between any two plants within a row, six plants arranged in the first row, two plants in the second row, and the remaining two plants arranged in the third row. Thus, the participants in the six-, eight-, and 10-plant conditions were asked to learn about the plants of the first row, the first two rows, and all three rows, respectively. Partitions were set between any two plants so that the student couldn’t see any other plant when watching one of them. The individual operation of the experiment made it possible to strictly control the pace of experiment. In most cases, only one student stayed in a row and students were not able to communicate with each other.

For all six conditions, the learning about the plants was performed by two stages: plant recognition and leaf morphology knowledge acquisition. At the stage of recognition, the students accessed the hypertext learning materials by either manually searching and clicking the correct pictures corresponding to the target plants for the manual search selection condition or scanning the QR codes attached to the target plants for the QR code selection condition, and then a 9-point Likert rating scale was presented on the screen of the mobile device, asking the students to indicate their cognitive load imposed in obtaining the access to the learning materials, with 1–9 being extremely low, very very low, very low, low, neither high nor low, high, very high, very very high, extremely high, respectively (see Paas, 1992; Paas, Tuovinen, Tabbers, & Van Gerven, 2003).

All students were allowed to use as much time as they needed to recognize the plants at this stage, regardless of the selection condition or the number of target plants. At the stage of leaf morphology knowledge acquisition, all participants followed the same procedure, reading the four screens of learning materials for each plant and then indicating their cognitive load resulting from learning about each plant of the leaf morphology on the same 9-point Likert rating scale, with 1 being extremely low and 9 being extremely high. However, the students were required to learn the leaf morphology within the learning time limit determined based on the results of a pilot study, 6 minutes for the conditions with six plants, 8 minutes for the conditions with eight plants, and 10 minutes for the conditions with 10 plants. At the start of the plant recognition and leaf morphology knowledge acquisition stages, the students were informed that the learning time was recorded and that they were only allowed to go forward in the learning materials once they began to communicate with each other. The scores of this test, together with the students’ final results of a natural science course in the last semester, were used to check whether the participants in the six experimental conditions did not differ in prior knowledge. Since all the text materials in the current experiment were presented in Chinese, the students’ final results of a Chinese-language course in the last semester, were also used as a factor to examine the validity of classification of conditions. Simple effect tests revealed no significant difference between the experimental conditions in their prior knowledge test scores, $F(5, 180) = .88, MSe = 3.15$, or their Natural Science, $F(5, 180) = .27, MSe = 30.18$, or Chinese language course results, $F(5, 180) = .63, MSe = 65.86$. Based on these results, it was decided not to use the prior knowledge test scores in any other analysis of the present study.
learn the next plant. A reminder of “your study is over, please return your mobile device to the researchers” was also presented on the screen when the learning materials corresponding to each condition were all read or when the setting time limit was up. In fact, only three students (1.6%) were not able to finish the learning within the time limit. However, because the students had also acquired some knowledge related to the questions in the tests they were still included in the final analyses.

Test phase. The test phase immediately followed the acquisition phase, consisted of a recognition test and leaf morphology knowledge test. Both tests were presented on the same laptop that was used at the beginning of acquisition phase. The recognition test consisted of a set of six multiple choice questions with five answer alternatives (pictures) for each question. The six-item multiple choice questions were compiled based on the learning materials designed for the conditions with six plants, which were also included in the learning materials for all other conditions and were thus considered as the baseline of the knowledge presented by the learning materials in the present study. The students were presented with a plant name and five pictures of plants, from which they had to choose the picture that corresponded to plant name. At the end of the multiple choice questions, a 9-point Likert scale displaying the cognitive load in completing the above six questions was administered to the students.

The leaf morphology knowledge test immediately followed the plant recognition test, including tasks separately used to examine the understanding of knowledge about leaf characteristics (drawing and assembling questions) as well as its application in novel plants (multiple choice questions). The students were first required to complete a 13-item drawing and assembling task in which four types of venation and four types of margins needed to be drawn, and five types of phyllotaxy needed to be reconstructed using artificial leaves and stems, with a time limit of 10 minutes. The drawing and assembling questions were designed to examine how much knowledge the students had acquired about leaf morphology from the acquisition. The use of assembling questions instead of drawing questions for testing the comprehension of phyllotaxy was chosen for two reasons. First, the concept of phyllotaxy involved spatial factors and physically assembling was assumed to be a better way to present in a three-dimensional perspective. Second, assembling question, to a certain extent, eliminate the possibility that the poor performance on comprehension of leaf morphology was due to a person’s inability to draw pictures. Following the drawing and assembling task, the students were given 6 minutes to indicate the specific subtype of leaf venation, margin, and phyllotaxy for six novel plants in pictures by the form of 18 multiple choice questions, three questions each plant, separately testing the types of venation, margins, and phyllotaxy. In this set of multiple choice questions, four answer alternatives were provided for the questions about venation and margins while five answer alternatives were provided for the questions about phyllotaxy. This task was used to investigate to what extent the knowledge of leaf morphology acquired during the acquisition phase could be transferred into new plants. Identically with the plant recognition test, after completing each of the tasks in the leaf morphology test, the students were required to rate the cognitive load on a 9-point Likert scale to indicate how much effort they spent on completing the tests.

Summary of variables and reliabilities. The dependent variables in this experiment included recognition test scores (six multiple-choice questions) and two task scores of the leaf morphology knowledge test (13 drawing and assembling questions and 18 multiple-choice questions) during the test phase. One mark was given for a correct answer giving a maximum score of 6 for the recognition test, and a maximum score of 13 and 18 separately for the two tasks of leaf morphology knowledge test. Responses presenting the leaf characteristic were considered to be correct in the drawing and assembling questions. The drawing and assembling questions were marked by the first author, and 30% of the questions were double marked by an experienced natural science teacher. The answer keys used by the raters provided synonyms where appropriate. Given the objective nature of the tests, we obtained a correlation of .84 between raters. Tests of reliability using Cronbach’s alpha of the 6-item multiple choice questions for the plant recognition test, and 13-item drawing and assembling questions and 18-item multiple choice questions for the leaf morphology knowledge test revealed scores of .64, .68, .72, respectively.

A fourth dependent variable in this study was cognitive load self-ratings on both the plant recognition and the leaf morphology knowledge tests during the test phase as well as during the acquisition phase (Paas & van Merriënboer, 1994). Cronbach’s alpha revealed a high internal consistency reliability of cognitive load self-ratings for the learning tasks during the acquisition phase. More specific, tests of reliability of the 6-, 8-, and 10-plant cognitive load self-ratings were .90, .94, and .98, respectively for the first learning stage of plant recognition, and were .94, .94, and .95, for the subsequent learning stage of leaf morphology knowledge acquisition. The cognitive load imposed in completing each of tasks during the test phase was rated only once, therefore, internal consistency on this measure could not be estimated.

The amount of learning time spent during the acquisition phase provided the last dependent variable. The time used to recognize plants (the average number of seconds spent on recognizing each plant) and to acquire the leaf morphology knowledge (the average number of seconds spent on learning about each plant, including four screens) during the acquisition phase were separately recorded within the time limit of learning tasks, which together with the cognitive load self-ratings during the acquisition phase were used to explain the test performance during the test phase.

Results

Data were analyzed in three steps. First, analyses were conducted on participants’ performance on the plant recognition test to examine differences in learning to recognize the plants between various conditions, with the dependent variables being multiple choice questions accuracy scores and the associated cognitive load self-ratings. Second, analyses were carried out on participants’ performance on the plant knowledge tests to investigate any differences in acquiring the leaf morphology knowledge across the various conditions, with the dependent variables being drawing and assembling question accuracy scores and multiple choice questions accuracy scores as well as their associated cognitive load self-ratings. Third, analyses were conducted on learning time spent on each of two learning stages (plant recognition and leaf morphology knowledge acquisition) and cognitive load self-ratings.
obtained after each stage of learning in order to estimate any difference in learning time and cognitive effort across diverse conditions during the acquisition phase, which may contribute to explanations for learner performance during the tests. A series of 2 (Selection Condition: Manual search vs. QR code) × 3 (Number of Plants: 6 vs. 8 vs. 10) analyses of variance (ANOVA) were conducted for each of the dependent variables. Statistical significance for all tests was set at .05 level, unless otherwise indicated. Partial $\eta^2$ was used as the effect size index. Accordingly, the eta squared ($\eta^2$) values at or above .01, .06 and .14 suggest small, medium and large effect sizes, respectively (Cohen, 1988).

**Multiple Choice Questions Accuracy Scores and Cognitive Load Self-Ratings During the Recognition Test**

ANOVA were conducted on the recognition test scores and on the cognitive load self-ratings (See Table 2), revealing a significant interaction between the selection condition and the number of plants: for test scores, $F(2, 180) = 24.71, MSe = 34.92, p < .001$, partial $\eta^2 = .22$, and for cognitive load self-ratings, $F(2, 180) = 70.14, MSe = 86.92, p < .001$, partial $\eta^2 = .44$.

Simple effect tests were used to explain the significant interaction on the test scores as well as cognitive load self-ratings for the plant recognition test. An independent samples $t$ test for number of plants was first performed on test scores. For six and eight plants, the manual search selection condition (six plants, $M = 5.19, SD = 1.06$; eight plants, $M = 4.52, SD = 1.15$) outperformed the QR code selection condition (six plants, $M = 3.84, SD = 1.32$; eight plants, $M = 3.81, SD = 1.23$) on the test scores, $t(61) = 4.48, p < .001$ and $t(61) = 2.34, p = .002$, respectively. However, for 10 plants, a $t$ test revealed a reversed effect on the test scores of the manual search condition ($M = 3.40, SD = 1.30$), $t(58) = 5.04, p < .001$. Inspection of the means revealed that the QR code selection condition significantly outperformed the manual search condition on learning to recognize plants when the number of learning targets was increased to 10. For the cognitive load self-ratings, the analyses revealed a highly consistent result with the test scores, indicating that lower cognitive load always being accompanied with higher test scores. Specifically, a $t$ test revealed that the QR code condition (six plants, $M = 3.97, SD = 1.05$, eight plants, $M = 4.72, SD = 1.40$) experienced heavier cognitive load than the manual search condition (six plants, $M = 1.72, SD = .77$, eight plants, $M = 3.19, SD = 1.11$) on the recognition test when learning about six and eight plants, $t(61) = 9.72, p < .001$, and $t(61) = 4.79, p < .001$, respectively. In contrast, when learning about 10 plants, the heavier cognitive load was imposed on the manual search condition ($M = 7.63, SD = 1.00$) compared to the QR code condition ($M = 5.43, SD = 1.25$), $t(58) = 7.53, p < .001$.

**Table 2**

<p>| Means and Standard Deviations for Multiple Choice Question Accuracy Scores and Cognitive Load Self-Ratings during the Plant Recognition Test |
|---|---|---|---|---|---|
| | 6 plants | 8 plants | 10 plants |
| | (n = 32) | (n = 31) | (n = 30) |</p>
<table>
<thead>
<tr>
<th>M</th>
<th>SD</th>
<th>M</th>
<th>SD</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test scores</td>
<td>5.19</td>
<td>.96</td>
<td>4.52</td>
<td>1.15</td>
<td>1.87</td>
</tr>
<tr>
<td>Cognitive load</td>
<td>1.72</td>
<td>.77</td>
<td>3.19</td>
<td>1.11</td>
<td>7.63</td>
</tr>
<tr>
<td>QR code selection condition (n = 93)</td>
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<tr>
<td>6 plants</td>
<td>8 plants</td>
<td>10 plants</td>
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<tr>
<td></td>
<td>(n = 31)</td>
<td>(n = 32)</td>
<td>(n = 30)</td>
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<tr>
<td>M</td>
<td>SD</td>
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</tr>
<tr>
<td>Test scores</td>
<td>3.84</td>
<td>1.32</td>
<td>3.81</td>
<td>1.23</td>
<td>3.40</td>
</tr>
<tr>
<td>Cognitive load</td>
<td>3.97</td>
<td>1.05</td>
<td>4.72</td>
<td>1.40</td>
<td>5.43</td>
</tr>
</tbody>
</table>

Note. QR = quick response.

**Drawing and Assembling Question and Multiple Choice Question Accuracy Scores and Cognitive Load Self-Ratings during the Leaf Morphology Knowledge Test**

ANOVA were conducted for test accuracy scores and cognitive load self-rating on the two components of the leaf morphology knowledge tests: drawing and assembling questions, used for testing the knowledge understanding, and multiple-choice questions, used for testing the knowledge application (See Table 3).

**Drawing and assembling questions.** On the drawing and assembling task, for test scores, a significant interaction between the selection condition and the number of plants was found, $F(2, 180) = 4.08, MSe = 23.70$, partial $\eta^2 = .04$. An overall superiority of the QR code condition compared with the manual search condition was also significant for test scores, $F(1, 180) = 24.53, MSe = 142.62, p < .001$, partial $\eta^2 = .12$. For cognitive load self-ratings, neither the main effects nor the interaction were significant, $F(2, 180) = .10, MSe = .34$.

Simple effect tests were used to further explore the significant interactions for the test scores. For the learners in the manual search condition, there was no significant difference on the test scores between the conditions with different number of plants, $F(2, 90) = 2.46, MSe = 14.73$. In contrast, such difference was significant for the learners in the QR code condition, $F(2, 90) = 5.56, MSe = 31.40$, partial $\eta^2 = .11$. Post hoc Scheffé tests showed a statistically higher test score for the conditions with 10 plants compared to the conditions with six plants, indicating that the performance of learners using the QR codes during acquisition was significantly improved with the increased number of the plants from six to 10.

**Multiple-choice questions.** For the 18-item multiple choice questions, ANOVA indicated that the learners in the QR code condition consistently outperformed those in the manual search condition with higher test scores, $F(1, 180) = 19.12, MSe = 125.25, p < .001$, partial $\eta^2 = .10$, and lower cognitive load self-ratings, $F(1, 180) = 44.16, MSe = 55.50, p < .001$, partial $\eta^2 = .20$. The interaction between the selection condition and the number of plants was not significant for either test scores, $F(2, 180) = .15, MSe = .98$, or cognitive load self-ratings, $F(2, 180) = .06, MSe = .07$, indicating that the superiority of QR code condition compared with the manual search condition on learning of leaf morphology knowledge did not alter because of the number of the plants.
Table 3
Means and Standard Deviations for Accuracy Scores of Two Tasks as Well as Cognitive Load Self-Ratings During the Plant Knowledge Test

<table>
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<tr>
<th></th>
<th>Test scores</th>
<th>Cognitive load</th>
<th>Manual search condition (n = 93)</th>
<th>M</th>
<th>SD</th>
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<td>6 plants</td>
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<td>Test scores</td>
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<td>2.38</td>
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<td>5.32</td>
<td>2.61</td>
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<td>QR code condition (n = 93)</td>
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<td>6.84</td>
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Note. QR = quick response.

Learning Time and Cognitive Load Self-Ratings During the Acquisition Phase

ANOVA were carried out on the learning time and cognitive load self-ratings during the acquisition phase (see Table 4). The analyses were separately conducted for plant recognition and leaf morphology knowledge acquisition stages.

Learning time. For the initial plant recognition, the results demonstrated that the manual search condition spent statistically more time on learning than the QR code condition overall, F(1, 180) = 162.20, MSe = 4002.12, p < .001, partial η² = .47. The interaction between the selection condition and the number of plants was also significant during the stage of plant recognition, F(2, 180) = 5.95, MSe = 146.79, partial η² = .06.

A simple effects test on the time used for plant recognition was separately conducted for the manual search and the QR code conditions to further explore the significant interaction. For the manual search condition, an ANOVA showed significant differences between the conditions with different numbers of plants, F(2, 90) = 6.92, MSe = 285.23, partial η² = .13, indicating that the time spent on recognizing each plant differed in the manual search condition as a function of the number of plants. Post hoc Scheffé tests showed that the participants required more time to recognize each of the eight and 10 plants than to recognize each of the six plants. However, such differences on recognition time due to the number of the plants were not found on the QR code condition. ANOVA revealed that recognition time in the QR code condition remained at the same level regardless of the number of the plants, F(2, 90) = .15, MSe = 1.19.

With respect to the time used to acquire the leaf morphology knowledge at the second stage of acquisition phase, however, results revealed a reversed trend. The QR code condition spent statistically more time on learning than the manual search condition, F(1, 180) = 37.27, MSe = 1946.40, p < .001, partial η² = .17. An significant interaction between the selection condition and the number of plants was found, F(2, 180) = 3.13, MSe = 163.25, partial η² = .03. A simple effects test indicated no significant differences on learning time between the conditions with different numbers of plants for the manual search condition, F(2, 90) = 1.30, MSe = 48.56. In contrast, a significant difference was found due to the number of plants for the QR code condition, F(2, 90) = 9.29, MSe = 622.29, p < .001, partial η² = .17. Post hoc Scheffé tests revealed that the time spent on learning about leaf morphology was much more with 10 plants than with six and eight plants for the participants in the QR code condition.

Cognitive load self-ratings. The cognitive load self-ratings were consistent with the learning time, indicating that higher...
cognitive load was always accompanied with more learning time. At the plant recognition stage, overall higher cognitive load was imposed on the manual search condition consuming more learning time, $F(1, 180) = 408.44, MSe = 340.63, p < .001$, partial $\eta^2 = .69$. The interaction between the selection condition and the number of plants was significant, $F(2, 180) = 50.56, MSe = 42.17, p < .001$, partial $\eta^2 = .36$. Simple effects analyses revealed that the interaction reflected a positive relationship between cognitive load ratings and the number of plants in the manual search condition, $F(2, 90) = 77.90, MSe = 81.61, p < .001$, partial $\eta^2 = .63$, while the cognitive load ratings in the QR code condition were not differentially affected by the number of the plants, $F(2, 90) = .62, MSe = .39$.

At the stage of leaf morphology knowledge acquisition, results revealed higher cognitive load for the QR code condition than for the manual search condition, $F(1, 180) = 92.95, MSe = 66.75, p < .001$, partial $\eta^2 = .34$. The interaction between the selection condition and the number of plants was significant, $F(2, 180) = 3.30, MSe = 2.37$, partial $\eta^2 = .04$, indicating that the interaction was caused by the difference between the learners in the QR code condition, who rated a higher cognitive load for learning about 10 plants than for learning about 6 plants, $F(2, 90) = 6.27, MSe = 4.91$, partial $\eta^2 = .12$, and that the learners in the manual search condition, for whom the cognitive load ratings did not differ as function of the number of the plants, $F(2, 90) = .01, MSe = .004$.

In summary, results of the present study supported four major conclusions. First, for plant recognition, the manual search condition was more beneficial than the QR code condition with higher test scores and lower cognitive load when learning about six and eight plants. However, this advantage of the manual search condition was reversed at the highest number of target plants (i.e., 10 plants). Second, for leaf morphology knowledge acquisition, both the drawing and assembling test and the multiple choice question test revealed that learners using QR codes selection during acquisition significantly outperformed the learners using the manual search selection. However, based on the cognitive load self-ratings of the drawing and assembling task the superiority of QR code condition over the manual could not be statistically confirmed. Third, participants in the manual search condition spent more time on plant recognition during the acquisition phase, whereas the QR code condition spent more time on leaf morphology knowledge acquisition. Fourth, the cognitive load imposed during the acquisition phase was increased when spending more time on learning. Participants in the manual search condition devoted more mental effort in learning during the stage of plant recognition, while participants in the QR code condition devoted more mental effort in learning during the stage of leaf morphology acquisition.

**Discussion**

The overall goal of the present study was to investigate the effects of manual search selection and selection through QR codes on the acquisition of plant recognition knowledge and leaf morphology knowledge with different numbers of plants (6, 8, 10 plants) in a mobile device assisted learning environment. The findings of the experiment addressed whether and how using the QR code technology would facilitate each of the two stages of plant learning, and whether and how the effectiveness of QR codes on learning would be influenced by the number of plants. Both main hypotheses were supported by the findings in the present study. When learning to recognize the plants, the advantage of using QR codes, presented with higher test scores and lower cognitive load, was only apparent with the large number of the plants (i.e., 10 plants), whereas the small and medium number of plants (i.e., 6 and 8 plants) was better acquired using traditional manual search selection (Hypothesis 1). In contrast, when learning about leaf morphology, the QR code technology, as an offloading selection means to obtaining the access to learning materials, was more effective compared to the manual search selection for learning regardless of the number of the target plants (Hypothesis 2).

The first hypothesis was supported by the finding that the learner performance on the recognition test was higher and cognitive load self-ratings lower for the manual search condition when the number of learning targets was six and eight plants, while the performance was better for the QR code condition when the number of learning targets was 10 plants. During the learning stage of plant recognition, the learners in the manual search condition were presented with a number of pictures on the mobile device screen and they were required to repeatedly compare and contrast the pictures with the real plant in front of them in order to select the correct picture for each of the target plants and obtain access to the learning material. Compared with the automatic and direct access to the learning material by QR code technology, effortful manual selection of plants required much more working memory resources to differentiate the structural as well as surface features of the plants, which was essential to learning to recognize the plants. The schemas about the physiognomy characters as well as the details of the plants, therefore, could be constructed and stored in long-term memory and retrieved into working memory for facilitating recognition of the plants when required during the test. In contrast, such schemas were absent for the learners using QR codes, who could gain access to the learning materials without investing mental effort in the selection process. Consequently, there was nothing to retrieve from long-term memory that could assist them in recognition during the test. However, the limitation of working memory capacity requires all learning activities to be conducted with a tolerable amount of cognitive load. When the number of the plants to be learned was increased to 10, the cognitive load resulting from the manual search selection may have exceeded the working memory capacity, and consequently impeded learning.

The explanation for the number-dependent effect of QR codes on learning about plant recognition was further confirmed by an exploration of the detailed cognitive processes during the acquisition phase. By analyzing the time used for plant recognition as well as the subjective cognitive load rated after selecting each of the plants, it was found that the learners in the manual search condition spent considerably more time and more mental effort than the learners in the QR code condition in selecting the plants, regardless of the number of target plants during the acquisition phase. However, a substantial increase of mean cognitive load self-ratings from 2.97 and 3.63, for learning to recognize six and eight plants, respectively, to 6.07 took place for learning to recognize 10 plants with manual search selection. This suggests that a critical point concerning the number of the target plants might appear where the amount of cognitive load induced by manually selection of the plants overburdened working memory capacity.
Taken together, in the case of learning to recognize the plants, the superiority of using QR codes compared to using traditional manual selection was robust only when the number of plants was highest; otherwise, the selection through manual search, which induced the learners to focus on the structural features and the critical aspects of the target plants during acquisition, facilitated learning more than the selection with the offloading QR code technology. The present findings are consistent with the idea of presenting high-element interactivity materials in their full complexity within the working memory capacity for effective learning suggested by many studies of cognitive load theory (i.e., variability effect by Gao, Low, Jin, & Sweller, 2013; Paas & van Merriënboer, 1994). For example, van Merriënboer, Kester, and Paas (2006) proposed an instructional design principle of teaching complexity rather than simple tasks for a better transfer performance on the basis of the previous empirical studies (Paas, 1992; Paas & van Merriënboer, 1994; Renkl, 2002; van Merriënboer, Schuurman, De Croock, & Paas, 2002). By increasing the practice variability or reducing the guidance and feedback, more mental effort is required and deeper cognitive processes germane to learning are stimulated, resulting in better cognitive representations. The present study extended this design principle into the context of mobile learning, suggesting that manual selection is more effective than QR code selection as long as the cognitive load imposed by the learning task and the selection is within the limits of working memory.

The second hypothesis that the QR code technology would reduce extraneous cognitive load and facilitate learning about leaf morphology was also confirmed in the present study. It was found that both the drawing and assembling questions and multiple-choice questions of the leaf morphology knowledge test revealed better test scores for the QR code condition than the manual search condition. Moreover, the statistically lower cognitive load rated by the learners following the selection with QR codes compared to those following the selection with manual search in the multiple-choice questions further confirmed the advantages of using QR code technology in acquiring the leaf morphology knowledge. With respect to the nonsignificant difference of cognitive load self-ratings between the manual search and the QR code conditions across the learning with different numbers of plants in the drawing and assembling task, a possible reason is that the cognitive load rated by the learners might have been obscured by the load imposed by the drawing and assembling activities.

The advantages of using QR codes in acquiring leaf morphology knowledge can be understood with the consideration of the distribution of the working memory resources on the two consecutive learning tasks. In the present study, the learning about plants with the support of mobile devices included two consecutive tasks: plant recognition and leaf morphology knowledge acquisition. With respect to the second stage of leaf morphology knowledge acquisition, the first stage of plant recognition was only necessary for the procedure, by which the learners could access the electronic learning materials about leaf morphology on their mobile devices, but was not necessary for the content. The leaf morphology knowledge could be acquired without a need for the prior knowledge obtained by initial plant recognition. Thus, the initial plant recognition was meaningless to the acquisition of leaf morphology knowledge, using up limited working memory resources. In other words, the plant selection by manually searching, in comparison with the selection by QR code technology, apparently consumed more working memory resources at the stage of selection and allowed fewer resources to acquire leaf morphology knowledge. As a consequence, learning was impeded for the manual search condition regardless of the number of the plants. For the QR code condition, in contrast, the automatic recognition by scanning QR codes with the built-in camera of mobile devices decreased the consumption of working memory resources at the initial stage of selection, resulting in more working memory resources available during the subsequent stage of leaf morphology knowledge acquisition.

The explanations of depleted working memory resources for the relatively low performance of the manual search condition in the subsequent learning task about leaf morphology were further confirmed by analyzing learning time as well as the cognitive load self-ratings during the acquisition phase. It was found that the learners in the manual search condition reported lower cognitive load and spent less learning time than those in the QR code condition regardless of the number of target plants during leaf morphology during the acquisition phase. These results are suggestive for decreased motivation and mental effort of the participants in the manual search condition for a subsequent task due to exhausted working memory resources. Schmeichel (2007) indicated based on a series of empirical experiments that executive control resources are limited; initial efforts at executive control reduce subsequent efforts at executive control. According to the ego depletion effect, the self-control or willpower drawing on some limited mental resources is impaired on a subsequent task after experiencing a depleting task also requiring self-control (Baumeister, 2002; Baumeister, Bratslavsky, Muraven, & Tice, 1998; Inzlicht & Schmeichel, 2012). In the current study, the learners with manual search selection worked very hard in the initial plant recognition, and might feel they have finished their part for the experiment and deserve a break, especially when the subsequent learning became optional in a sense because the learners were not required to complete any task at this stage. The less time spent on learning about the leaf morphology for the manual search condition also revealed their low mental effort in this task. In contrast, the learners with effortless QR code technology did not need to devote mental effort at the initial selection stage and they might feel their learning had just begun at the stage of leaf morphology acquisition. High mental effort contributed to schema construction.

The present study was consistent with the previous studies regarding the detrimental effects of extraneous cognitive load (e.g., Chandler & Sweller, 1991; Cooper & Sweller, 1987; Sweller, 1994, 2003, 2004, 2010b), which suggested that the activity that does not directly contribute to learning may induce unnecessary cognitive load, which consumes limited working memory resources and should be reduced. However, most previous studies examined this effect based on the concurrent processing of multiple sources of information whereas the present study explored the contribution of working memory resources in two-stage learning, indicating a subsequent-task effect. When the two different learning tasks are given to the learners in succession without time intervals, even if the cognitive resources are available separately for each of the two tasks, the learners may experience a temporary reduction in their capacity or motivation to devote their working
memory resources to the subsequent learning tasks after high consumption of cognitive resources on the initial learning task.

Limitations

One limitation of this study was the relatively low internal consistency of the tests. The small number of test questions is a possible reason for the reduced Cronbach’s alpha value (Nunnally & Bernstein, 1994). In order to make sure that the learners with the different numbers of target plants (6 vs. 8 vs. 10) during acquisition could be provided with an exactly identical measure on the plant recognition test, the test questions could only be designed based on the minimum number of target plants, otherwise the questions could exceed the range of knowledge acquired by the learners with six plants. As a consequence, only six multiple-choice questions were prepared for testing the plant recognition, one question for each plant. Similarly, due to the limited subtypes of leaf morphology (13 subtypes in total), we only had 13 drawing and assembling questions to test the understanding of leaf morphology knowledge, and 18 multiple-choice questions for the application test to avoid redundancy on testing contents. Future studies are expected to test the number-dependent QR code effect in the other context without the limitation of the learning targets and thus could have more questions during the tests for higher internal consistency reliability.

The current research, based on the learning time as well as cognitive load self-ratings during the acquisition phase, pointed out that depleted motivation and mental effort might result in inferior performance of the manual search condition in the subsequent learning task, but did not measure motivation directly, constituting a second limitation. Future work using motivation evaluation techniques may try to collect direct motivational data to help explain performance on consecutive learning tasks. Furthermore, measurement on both cognitive load and motivation may help to shed light on the possible relationship between exhausted working memory capacity and depleted motivation.

Educational Implications

In summary, the effectiveness of using QR code technology on learning about plants with the supported of mobile devices was evident in this empirical work; however, the effectiveness depended on the number of learning targets and the specific learning purpose. The findings were in accordance with the hypotheses, proposing a subsequent-task effect. Not only does working memory capacity differ between individuals, but also it fluctuates within individuals over time. The results of this research may have general implications for using technology in educational context. Technology has been increasingly used in the current classrooms. However, in many cases the use of the technology lacks guidance and causes heavy cognitive load. The major concern of this study was to make suggestion for the effective use of the QR code technology in learning about plants, but the results should generalize to learning targets other than plants with the support of QR codes. The effects of the QR codes on learning need to take account of both the amount of learning contents and the learning goal. If the learning goal is relevant to recognition itself, the use of QR codes will not be recommended because it restricts the genuine learning processes—unless the cognitive load resulted from the traditional manual search selection exceeds the working memory capacity. Alternatively, if the learning goal is to deal with tasks other than recognition, such as to acquire the stored information with the mobile devices, the use of QR codes decreases the consumption of cognitive resources at the initial stage of recognition, and benefits the subsequent learning about the information.

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