Looking Deeper: Using the Mobile Microscope to Support Young Children’s Scientific Inquiries

Pao-Nan Chou 1,* and Ping-Jhen Wang 2

Abstract: This study adopted a quasi-experimental design with the support of qualitative information to investigate the impact of the mobile microscope on students’ science learning outcomes in a laboratory setting. The duration of the educational experiment was 5 weeks. Research participants comprised 56 third graders from two different classes at a public elementary school in Taiwan. Two classes with an equal number of students formed the experimental and control groups. Students in the experimental group employed mobile microscopes to support their scientific inquiries, whereas students in the control group used only tablet computers to facilitate their science learning. A standardized test was developed to measure students’ basic understanding of botany. Additionally, semi-structured concept mapping was employed as an alternative non-standardized test to evaluate students’ natural science learning. The quantitative findings indicated a significant instructional effect in the students’ concept mapping but not in the standardized test. The qualitative results revealed that mobile microscopes might motivate students to actively engage in knowledge discussion and sharing during plant observation.

Keywords: mobile microscope; tablet computer use; natural science learning; experimental study

1. Introduction

Because of the wide availability of mobile devices (smart phones or tablet computers) in educational settings, several studies have explored the integration of mobile learning into classrooms and confirmed the utility of mobile learning as an effective learning strategy for promoting student learning [1,2] Instructional benefits such as active learning for knowledge development and increased learning motivation were frequently reported during students’ learning process [3,4] However, according to Zydney and Warner’s systematic review of mobile learning [5], a majority of the related literature has emphasized the software component (i.e., application integration), and only a few studies has investigated the use of hardware tools in mobile devices for various teaching purposes.

Following technological advances in the imaging capabilities of mobile devices, the mobile microscope is a newly developed hardware tool for microscopy applications [6]. From a cost perspective, two types of mobile microscopes exist: standard and low-cost models. The former constitutes a small microscope lens mounted on the mobile phone (or tablet computer) camera via a lens tube and eyepiece, and the latter is a tiny glass lens attached to the mobile phone (or tablet computer) camera through clay or tape [6]. Both models provide a magnification imaging system, however, the standard model likely yields a higher magnification effect. The application of mobile microscopes in classroom teaching, particularly to support students’ scientific inquiries, has not been explored in the existing literature. Accordingly, the current study integrated mobile microscopes into an elementary school’s science curriculum to investigate the effect of mobile microscopes on young students’ learning effectiveness.

Our research team collaborated with a public elementary school in Taiwan to develop a natural science lesson in which the low-cost mobile microscope was adopted to support
scientific learning activities. During the 5-week experimental lesson, students used tablet computers with a mobile microscope to conduct scientific inquiries in a science laboratory. Our research hypothesized that equipping students with mobile microscopes would improve their learning potential, thereby leading to different learning outcomes. Specifically, the following was a major research question of the study:

RQ: How were students’ learning performances measured in standardized (criterion) and non-standardized (concept mapping) tests after using mobile microscopes to engage in scientific learning activities?

2. Literature Review

2.1. Mobile Learning in Science Education

Mobile learning entails the use of mobile devices to support student learning [7]. This application presents a crucial educational trend that may completely transform teaching practices and learning styles in educational settings [8]. Zydney and Warner argued that mobile learning is more relevant in science education than in other academic disciplines [5], because the mobility awarded by mobile devices enables students to explore natural environments outdoors or observe experiments within classrooms. For example, in Hwang et al.’s study, students used personal digital assistants (PDAs) to perform scientific activities in a science park [9]. Chou and Feng reported students’ employment of tablet computers to record their experimental results in a science laboratory [2]. A detailed literature review revealed that researchers have identified positive learning outcomes in terms of student attitude or engagement when mobile learning was completely integrated into elementary school science curriculums.

2.2. Mobile Learning in Nature Science Domain

Short-term instructional experiments, outdoor scientific inquiries, and application of mobile devices as research tools are the common characteristics of the research design of past studies exploring the integration of mobile learning in natural science education [5]. For instance, Huang et al. developed a mobile plant learning system in which students employed PDAs to observe different plants on campus [10]. The duration of the instructional experiment was only 4 h. Additionally, Hwang et al. integrated an interactive concept map into the mobile learning system in which students used PDAs to investigate insects’ growth in a butterfly garden [11]. This experiment also involved a one-shot data collection (4 h). Chiang et al. incorporated augmented reality into an interactive mobile learning lesson [12]. In the 2-h experiment, students used tablet computers to observe outdoor plant systems. Unlike previous research, the current study adopted a longer experiment period, indoor science learning activities, and a hardware-based mobile microscope as a research tool.

2.3. Instructional Objectives of Mobile Learning in Science Education

Gay et al. developed the term “mobility hierarchy” to categorize four levels of instructional objectives in integrating mobile technology into educational environments [13]. In the framework of mobility hierarchy, lower levels represent less advanced technological application. For example, in level three, mobile learning focuses on capturing and integrating data, indicating that the applications (app) in mobile devices enable students to conduct data collection or synthesis. Although previous empirical research in science education has not specified the level of mobile learning they adopted, their reported research procedure and applications used could be evidently categorized into level three. The current study’s technological application can also be classified into level three.

2.4. Instructional Methods of Mobile Learning in Science Education

1:1 computing or Bring Your Own Device (BYOD) is an instructional method that allows individuals the opportunity to use mobile learning in class. This method emphasizes the importance of equipping each student with a personal mobile device [1]. For instance, Looi et al. reported that students used their school-assigned mobile phones to study science
learning content (body systems lessons) [14]. In Song’s study, students were required to bring their own mobile phones to perform several inquiry-based learning activities (fish anatomy) during a science class [15]. However, probably owing to potential student behavior issues, most related studies have refrained from adopting the 1:1 computing or BYOD approach. The current study also did not adopt this trend because of the school administration policy.

2.5. Instructional Procedures of Mobile Learning in Science Education

Instructional procedures concerning mobile learning vary greatly in science education according to the learning objectives of scientific inquiry tasks. Researchers may adopt existing models or develop their own procedures. For example, in Song’s study, the proposed instructional procedure shared similarities with engineering design processes and comprised six stages: (a) engage (in class), (b) explore (outside the school), (c) observe (in school laboratory), (d) explain (in school laboratory), (e) reflect (online activities), and (f) share (online and in class) [15]. In each stage, students were required to use their mobile phones to achieve learning goals in different locations. In Chou et al.’s study, group projects in a science laboratory were emphasized for science learning, and self-developed instructional procedures were simplified through four stages: (a) preparation, (b) orientation, (c) observation and exploration, and (d) presentation. Students used tablet computers only in the last two stages. For application in a science learning context, the current study adapted Chou et al.’s four-stage model [2].

2.6. Mobile Microscope Use in Classroom

The mobile microscope in the current study is defined as a combination of mobile technology and a microscope. The use of the microscope is mounted on the camera of mobile devices (mobile phones or tablet computers). Because the use of mobile microscopes in education is in its infancy, previous related studies tended to focus on image development of the microscope lens or other hardware features of the microscope [6]. No empirical studies have investigated the effects of the mobile microscope in classrooms. In this context, student learning with mobile microscopes remains unexplored.

3. Research Methods

3.1. Research Design

The study adopted a quasi-experimental pretest and posttest design with the support of qualitative information to investigate the research question. In the quantitative component, the independent variable was the use of varied instructional tools (a tablet computer with or without the microscope); the dependent variables were the two types of natural science learning outcomes (evaluated through standardized and non-standardized tests). In the qualitative component, two types of information were collected to supplement the quantitative data [16], which included students’ learning responses from teacher observation during the experiment, and students’ informal interviews after the experiment. Figure 1 depicts the study’s research design.

![Figure 1. Research design of the study.](image-url)
To prevent extraneous variables from influencing the experiment’s validity [17], the study controlled research conditions through the following factors:

1. Class instructor: The same instructor taught the learning content in both the experimental and control groups. The instructor had experience using mobile devices to support student learning.
2. Class time: The class time in both experimental groups was identical. Each class time was 40 min.
3. Learning content: Students in two groups received the same learning material.
4. Class setting: Students in the experimental and control groups engaged in learning activities in the same laboratory.
5. Test implementation: The pretest and posttest were administered for two groups of students in the same week.
6. Learning activity: Instructional design in two groups was the same. Students followed the same learning procedures.

3.2. Research Participants

The sample population comprised 56 third graders from two classes at a public elementary school in Taiwan. Two classes with an equal number of students (Class A: 28, Class B: 28) formed the experimental and control groups. To improve students’ science learning, students in both groups were assigned into different teams by following the heterogeneous group principle suggested by Chou et al [18]. Prior to the study, students in both groups had experiences of engaging in scientific observation using tablet computers. Additionally, students in the experimental group received educational training on the use of the mobile microscope before commencement of the experiment.

3.3. Tools for Measuring Learning Outcomes

The current study developed a standardized test comprising a pretest and a posttest to assess students’ learning outcomes in basic botany. The test covered the following five learning areas: (a) understanding of plants, (b) methods and tools for studying vegetable plants, (c) problems and solutions concerning vegetable planting, and (d) the vegetable growing process. The test consisted of 20 multiple choice questions. The test’s score range was between 0 and 100, with higher scores representing higher learning achievement in basic botany. Table 1 presents some representative multiple choice questions.

Table 1. Representative multiple choice questions.

| Multiple-Choice Questions                                                                 |
|------------------------------------------------------------------------------------------|
| When you see several small holes on vegetable leaves, the major reason is (a) too much water, (b) soil is too dry, (c) bugs ate the leaves, (d) malnutrition on vegetable |
| Which ways can allow the vegetables to grow better: (a) fertilization routinely, (b) do not uproot weeds, (c) let the soil dry, (d) change the soil daily |

The study adopted a three-stage procedure to ensure the tests validity and reliability. First, three science teachers from a public elementary school were invited to evaluate the draft of test items. Expert validity was established at this stage. Subsequently, a revised test was administered among 25 fourth graders who had already learned the content. An item analysis was performed to confirm the content validity during this stage. The initial 35 questions were reduced to 20 questions after removal of the test items that did not meet the requirements of the discrimination index (>0.2). Finally, the result of a KR-21 analysis revealed a reliability coefficient of 0.89, indicating the test’s good condition on the basis of the test evaluation standard suggested by Aiken and Groth-Marnat [19].

Rice et al. highlighted concept maps as an alternative measurement tool for science learning [20]. In the current study, in addition to the standardized test, a semi-structured concept map was developed to assess students potential learning outcomes. In the concept
map, several scaffolding components related to the learning content were provided to support student thinking [21]. Under the designated components, students summarized the major concepts related to the learning content in basic botany. The students scored a point for each concept that was presented accurately. A higher score indicated better knowledge acquisition in basic botany [11]. Figure 2 presents a concept map designed by the instructor.

![Concept Map](image)

**Figure 2.** Semi-structured concept map.

### 3.4. Qualitative Data

In this study, because all students had experiences using the tablet computers to engage in scientific learning before, the learning variations identified in the experimental group (the tablet computer with the mobile microscope) was the focus for qualitative data collection, which provided an insight into how the mobile microscope supported student learning. The control group only served as a traditional teaching style.

The qualitative data contained two parts, namely direct observation by the instructor and informal interviews with the students. During the weekly experiment process, the instructor documented students’ learning statuses (the experimental group) in a teacher’s observation report. Upon the completion of the 5-week experiment, the students appeared for an informal interview without an interview guide. An unstructured interview entailed a 30-min informal conversation with 10 experimental group students. After data collection, the researchers examined two sources of qualitative information through data comparison to ensure the trustworthiness of qualitative findings.

### 3.5. Mobile Microscope

In the study, students in the experimental group employed low-cost mobile microscopes to support their scientific inquiries in science class. When using the microscope, students needed to mount a tiny glass lens on their tablet computer’s camera using sticky clay (Figure 3). Increasing the number of glass lenses offered a considerable magnification effect. Figure 4 demonstrates how students used mobile microscopes in the science class.
Figure 3. Low-cost mobile microscope. (left) microscope lens (right) the microscope mounted on the tablet computer.

Figure 4. Students using the mobile microscope in science class.

Students in both the experimental and control groups used tablet computers in the science class. The provision of mobile microscopes was the major difference in the experimental group. All students used the built-in camera in the tablet computer to obtain plant images. Subsequently, they collaboratively shared their findings pertaining to the images. Students in the experimental group were likely to capture regular and magnified images. Figure 5 presents the regular and magnified images of carrot skin.

Figure 5. Carrot skin in regular (left) and magnified (right) images.
3.6. Research Procedure

Prior to the study, a standardized test was conducted as a pretest to measure students’ existing knowledge. During the 5-week educational experiment, students performed weekly 120-min scientific activities at the science laboratory. While experimental group students used tablet computers with mobile microscopes, control group students employed tablet computers (the built-in camera) alone to observe plants. Upon completion of the experiment, the same standardized test was administered with different item numbers among all students as a posttest. Subsequently, students were also required to complete semi-structured concept maps. Figure 6 presents the study’s research procedure.

The current study adopted Chou et al.’s model to establish a three-stage instructional procedure: orientation, observation, and presentation [2]. The sequential procedures offered a teaching framework to facilitate the 120-min scientific inquiries of students of both groups. In the first stage (orientation: 40 min), the students received weekly instructional content regarding vegetable planting and plant-observation techniques. In the second stage (observation: 50 min), teams of students took turns to observe plants using assigned tools. In the final stage (presentation: 30 min), each team presented their plant images by connecting the tablet computer to a projector.

3.7. Data Analysis

In the study, regarding the quantitative data, a t-test was employed to measure students’ progress between the pretest and the posttest and evaluate students’ learning outcomes in concept mapping. One-way analysis of covariance (ANCOVA) was employed to observe the effect of different learning tools on students’ learning performances (standardized test). Regarding the qualitative data, interview data were transcribed and comparatively analyzed using the teacher’s observation report.

4. Results and Discussion

4.1. Students’ Learning Performance in the Standardized Test

The results of the paired t-test and one-way ANCOVA are summarized in Tables 2 and 3. The results indicated that students’ science learning in both the experimental ($t = 7.73, p < 0.01$) and control groups ($t = 5.73, p < 0.01$) was significantly improved. Students in the experimental group (18.85) demonstrated superior learning improvement compared with the control group students (15.71). However, when the pretest was rigorously controlled ($F = 37.89, p < 0.01$),
no significant difference was identified in the posttest results \((F = 2, p > 0.05)\) between the experimental and control groups. In other words, the pretest results revealed identical student learning performance in the experimental and control groups.

Table 2. Results of the paired \(t\)-test.

|          | \(n\) | Posttest–Pretest | Pretest M | Pretest SD | Posttest M | Posttest SD | \(t\) | \(df\) |
|----------|-------|------------------|-----------|------------|-----------|------------|-------|-------|
| Experimental | 26    | 18.85            | 55.58     | 17.22      | 74.42     | 13.88      | 7.73 **| 52    |
| Control   | 28    | 15.71            | 51.25     | 15.91      | 66.96     | 17.66      | 5.73 **| 52    |

Note: Two students dropped out from the experimental group. **\(p < 0.01\).

Table 3. Results of the one-way ANCOVA.

| Source                  | SS      | \(df\) | MS | \(F\) | \(p\)   |
|-------------------------|---------|--------|----|-------|---------|
| Covariance: Pretest     | 5640.92 | 1      | 5640.92 | 37.89 | 0.00 ** |
| Instructional Treatment | 297.15  | 1      | 297.15 | 2     | 0.16    |
| Errors                  | 7592.39 | 51     | 148.87 |       |         |

**\(p < 0.01\).

4.2. Students’ Learning Performance in the Concept Mapping

Table 4 presents the results of the independent \(t\)-test. A significant difference was observed between the experimental and control groups \((t = 7.85, p < 0.01)\) in the semi-structured concept maps. In other words, the experimental group students performed significantly better than their counterparts in the control group in the non-standardized test.

Table 4. Results of the independent \(t\)-test.

|          | \(n\) | \(M\) | \(SD\) | \(t\)-Test |
|----------|-------|-------|--------|------------|
| Experimental | 26    | 29.04 | 6.29   | \(t = 7.85 \) ** \(df = 53\) |
| Control   | 28    | 17.50 | 4.50   | –          |

Note: Two students dropped out from the experimental group. **\(p < 0.01\).

4.3. Qualitative Observation and Informal Interviews

Results of the qualitative analysis of the teacher’s observation and students’ informal interviews could be divided into four major themes: learning motivation, collaborative learning, different learning experience, and technical problems. Table 5 summarizes the themes with representative quotes from the observation and the interviews.

Overall, all students had experiences using the camera feature on the tablet computers to record their scientific investigation. Students in the control group received instruction identical to the previous teaching model. The learning variations only existed in the experimental group. The instructor was fully familiar with students’ traditional learning behaviors (using the camera feature), which served as a baseline for the instructor’s observation judgement on learning variations (using the mobile microscope) in the experimental group.

The qualitative findings suggested that students in the experimental group actively engaged in plant observation through the mobile microscope despite minor technical problems. Overall, experimental group students showcased positive learning attitudes and behaviors during the educational experiment.
Table 5. Results of the qualitative analysis.

| Themes                                           | Representative Quotes                                                                                                                                                                                                 |
|--------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. Learning motivation: students motivated to learn something new | “It was very interesting to see many unexpected things. I never knew that the tablet computer could be combined with the microscope. The new gadget motivated me to see beyond what meets the eye” (Student)  
“After taking regular pictures, students were eager to capture magnified images. They wanted to know what plant specimens looked like under the mobile microscope. Students paid more attention to the magnified images of plants.” (Instructor) |
| 2. Collaborative learning: discussion with peers  | “The magnified images were so amazing. I never knew that the carrot skin could be seen in this manner. I was eager to share the images with my team members. We held discussions on the images.” (Student)  
“Teams of students took turns to use the mobile microscope. Once students obtained the magnified images, they were eager to share their results by discussing it with peers.” (Instructor) |
| 3. Different learning experience: looking deeper  | “I have used the tablet computer before to take regular images. Because the regular images and the view from the naked eye were similar, I would not carefully examine the images. But the magnified images offered me a whole new learning experience. Now, I want to learn more about the magnified images.” (Student)  
“The mobile microscope was highly attractive to students. Whenever students identified something new, sounds of excitement filled the science laboratory. The mobile microscope seemed to offer a new learning experience to students. They sometimes asked me if they could take magnified images of human body parts such as hands instead of plants.” (Instructor) |
| 4. Technical problems: more practice required for taking pictures | “It is easy to capture magnified images. But obtaining clear magnified images requires practice. Adjusting the focus of the lenses was a big task.” (Student)  
“In the first two weeks, students often struggled with adjusting the focus of the lenses. I had to assist them with focusing accurately. Once the students became familiar with the procedures, they faced no problems in capturing clear magnified images.” (Instructor) |

4.4. Overall Discussion

After the 5-week educational experiment, students in both the experimental (with the mobile microscope) and control groups (without the mobile microscope) demonstrated significant learning progress in the domain of natural science. In other words, from the perspective of learning improvement, tablet computers may have the potential to facilitate students’ science learning in the science laboratory and their engagement in natural science activities without support from mobile microscopes [2,12,15].

Although the learning progress of students in the experimental group surpassed that of those in the control group, no significant instructional effect was observed between the two groups of students in the standardized test. This finding did not support our initial research assumption concerning the use of mobile microscopes. In other words, with the assistance of the mobile microscope, students may obtain abundant micro insights (i.e., magnified images) into different types of plants; however, those novel science learning experiences may not drive them to strengthen their cognitive understanding of regular learning content.

In contrast to the standardized test, the non-standardized test (concept mapping) demonstrated a significant instructional effect between the two groups. This finding can be attributed to the test format. In the standardized test, students had to only select answers from limited question items. A test format such can stymie students’ thinking process. However, in the concept mapping test, students represented their knowledge by adding their science experiment experiences. Students who used the mobile microscope might have been familiar with more concepts concerning magnified images than their
counterparts without the mobile microscope. Concept mapping provided students with an opportunity for an open-ended knowledge representation [22].

Although statistical findings only confirmed the instructional benefit of mobile microscopes in non-standardized (concept mapping) learning outcomes, the qualitative results offered a fascinating perspective on the complete integration of mobile microscopes into students’ scientific inquiries. Once students are skilled in obtaining magnified images, the mobile microscope has the potential to serve as a novel technological tool to promote students’ active engagement in scientific discussion and sharing. However, because the participating students engaged in only 5 weeks of science learning with the mobile microscope, the technology’s novelty may have led to the aforementioned phenomenon [23].

5. Conclusions

This study investigated the impact of mobile microscopes on students’ science learning in a laboratory setting. The quantitative statistical analysis demonstrated no significant difference between students with or without the mobile microscope in the standardized test (traditional multiple choice questions). However, in the non-standardized test (semi-structured concept mapping), students using the mobile microscope outperformed those who used only the tablet computer. Furthermore, the qualitative data analysis indicated that the mobile microscope offered students a whole new science learning experience and motivated them to engage further in plant observation.

Because of the design of this experimental research, the study findings may not be generalizable to other science learning scenarios. Future studies examining the use of mobile microscopes may consider the research limitations of our study. First, the use of mobile microscope in the study was restricted by a team-based model. Future studies may adopt a 1:1 computing strategy to promote individual use of the mobile microscope. Second, owing to the school’s limited budget, the current study used only low-cost mobile microscopes. Future studies may attempt to employ the standard mobile microscope to obtain better magnification effects during plant observation. Third, the study mainly focused on students’ learning outcomes. Because the teacher’s expertise is closely related to student learning, future studies may investigate the role of the teacher when students use the mobile microscopes to engage in learning activities. Finally, science learning in our study occurred only in the laboratory. Future studies are recommended to allow students to use the mobile microscope to explore outdoor natural science.

Although the current study was conducted at an elementary school, the research implementation can still serve as a reference for educators who are interested in the adoption of mobile microscopes in classroom learning. First, manipulating the mobile microscope needs constant practice. To conduct an accurate observation, students should learn how to adjust the microscope focus to obtain a clear image. Second, for the purpose of deep learning, the instructor can increase the number of microscope lenses one at a time. Instructional strategies such as these can enhance students’ observation experiences. Finally, students’ presentation of magnified images is a necessary procedure for successful science inquiries. To facilitate the students’ learning process, wireless projection on the tablet computer presents a better instructional solution in terms of presentation.

Author Contributions: Conceptualization, P.-N.C.; methodology, P.-N.C.; formal analysis, P.-N.C. and P.-J.W.; investigation, P.-J.W.; data curation, P.-J.W.; writing—original draft preparation, P.-N.C.; writing—review and editing, P.-N.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding;

Conflicts of Interest: The authors declare no conflict of interest.
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