

Development of a Coding-Based E-Student Worksheet on Photosynthesis to Improve Students' Conceptual Understanding at Wirabhakti Integrated High School

Muh. Afif Mayango, Masra Latjompoh(*), Devi Bunga Pagalla,
Elya Nusantara, Novri Youla Kandowangko

Development of Biology, Faculty of Mathematics and Natural Sciences,
Gorontalo State University,
Jenderal Sudirman No. 6, Kota Tengah, Wumialo Subdistrict, Gorontalo City 96128, Indonesia

*Corresponding author: masralatjompoh@ung.ac.id

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Abstract

Background: *Photosynthesis involves interconnected and abstract biological processes that are difficult to visualize with conventional teaching materials. Research on code-enhanced digital worksheets for photosynthesis, particularly their validity, practicality, and contribution to conceptual understanding, remains limited. This study aimed to develop and evaluate a code-enhanced interactive digital worksheet on photosynthesis and effectiveness in improving students' conceptual understanding.* **Methodology:** *The study employed a Research and Development approach using the ADDIE model, consisting of Analysis, Design, Development, Implementation, and Evaluation. The product was tested with 15 eleventh-grade students at Wira Bhakti Integrated High School. Data were collected using expert validation sheets, learning implementation observation sheets, teacher and student response questionnaires, and conceptual understanding tests. Data were analyzed using descriptive percentages and normalized gain (N-Gain).* **Findings:** *The digital worksheet obtained material and media validation scores of 84.29% and 87.78%, respectively, indicating high validity. Practicality was demonstrated by learning implementation, teacher response, and student response scores of 96.18%, 97.92%, and 94.88%, respectively, all categorized as highly practical. Students' average score increased from 61.07 on the pretest to 86.73 on the posttest, with an N-Gain score of 0.66, indicating moderate improvement.* **Contribution:** *The findings provide preliminary evidence that the digital worksheet is valid and practical and may support conceptual understanding of photosynthesis. The contribution is a web-based worksheet integrating programmed interaction with animations, simulations, videos, quizzes, and learning activities.*

Keywords: ADDIE; Coding; Conceptual Understanding; Digital Worksheet; Photosynthesis



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INTRODUCTION

The rapid development of information and communication technology has expanded the use of digital learning media in science education. Interactive digital resources can provide students with opportunities to engage with multimedia content and participate more actively in learning (Musdalifah et al., 2024; Amalia et al., 2025). Photosynthesis is particularly challenging because students must connect microscopic structures and biochemical processes, including chloroplast structure, light-dependent reactions, the Calvin cycle, and environmental factors. Without adequate visualization, these interconnected concepts may be memorized without being fully understood (Hasanah & Wisanti, 2023; Novitasari & Puspitawati, 2022). Interactive digital worksheets can address this challenge by integrating visual and interactive learning activities. Previous studies have reported that such worksheets can support engagement, science process skills, and conceptual learning (Manurung & Anazifa, 2024; Sundari et al., 2025).

Preliminary observations at SMA Wira Bhakti Integrated High School showed that photosynthesis learning still relied mainly on lectures, textbooks, printed worksheets, PowerPoint presentations, and videos, while interactive digital media were limited. The teacher reported that students had difficulty understanding the light and dark reactions, chloroplast functions, and relationships among the components involved in photosynthesis. The existing printed worksheets also could not visualize photosynthesis interactively. These findings indicate a need for a more interactive and visual learning medium.

Interactive digital worksheets have been developed using guided inquiry, problem-based learning, discovery learning, and other pedagogical approaches. For photosynthesis, Maulida & Yuliani (2023) showed that an interactive worksheet can support visualization of abstract processes. Other studies similarly reported that digital worksheets can be highly valid and practical for biology learning (Ardiansah & Zulfiani, 2023; Milatti & Fitrihidajati, 2024; Alivia & Purnomo, 2025).

In the present study, programmed interaction refers to the use of web technologies to implement interactive functions rather than to teach coding as a learning objective. The worksheet was developed using HTML, CSS, and JavaScript to integrate navigation, animations, simulations, quizzes, and responsive learning activities. These features allow students to interact with learning content and visualize processes that are difficult to observe directly.

However, research on code-enhanced digital worksheets for photosynthesis, particularly their validity, practicality, and contribution to conceptual understanding, remains limited. This study addresses that gap by developing a code-enhanced interactive digital worksheet specifically for photosynthesis and examining its validity, practicality, and preliminary learning improvement in a limited classroom trial.

Accordingly, this study aimed to develop a code-enhanced interactive digital worksheet on photosynthesis using the ADDIE model and to examine its validity, practicality, and preliminary contribution to students' conceptual understanding at SMA Wira Bhakti Integrated High School. The contribution of the study lies in

integrating programmed web-based interaction with multimedia learning features in a single worksheet designed for an abstract biology topic.

METHOD

Research Design

This study employed a Research and Development (R&D) approach using the ADDIE instructional design model, consisting of Analysis, Design, Development, Implementation, and Evaluation. The limited implementation used a one-group pretest-posttest pre-experimental design to obtain preliminary evidence of changes in conceptual understanding. The study was conducted during the second semester of 2026 at SMA Wira Bhakti Integrated High School, Gorontalo.

Ethical Considerations

Permission to conduct the study was obtained from SMA Wira Bhakti Integrated High School before data collection. Participant data were handled confidentially, and students' identities were not reported in the research results. The study was conducted within the school's regular learning activities.

Participants

The limited field trial involved 15 Grade XI students of SMA Wira Bhakti Integrated High School who were selected purposively because they had studied the prerequisite biology concepts and were learning photosynthesis. One biology teacher participated in the practicality evaluation, and one observer assessed learning implementation. The trial was conducted over two meetings.

Research Instruments

Six instruments were used. The material validation sheet assessed content feasibility, material presentation, conceptual-understanding alignment, and language, while the media validation sheet assessed product suitability, presentation, conceptual-understanding support, and language. The validation sheets used a five-point Likert scale (1–5). The learning implementation observation sheet used a four-point scale (1–4) to assess the implementation of planned learning activities. The teacher and student response questionnaires also used a four-point scale (1–4) and assessed interest, ease of use, material and presentation, learning benefits, conceptual-understanding support, and language/visual presentation. The conceptual understanding test consisted of 15 multiple-choice items covering interpretation (items 1–2), analysis (3–5), evaluation (6–8), explanation (9–10), problem solving (11–12), decision making (13–14), and integration of photosynthesis concepts (15). The five-point validation scale refers to [Oktaviara & Pahlevi \(2019\)](#).

Data Collection

Validation data were collected after expert review of the developed digital worksheet. During the two-meeting limited trial, the teacher used the web-based worksheet as the main learning medium and students accessed it through internet-connected devices. Learning implementation was observed by one observer. Teacher

and student responses were collected after use of the product, while pretest and posttest were administered before and after the learning intervention, respectively.

Procedure

The research procedure followed the ADDIE model. During Analysis, curriculum requirements, student characteristics, learning problems, photosynthesis content, and available facilities were examined. During Design, learning objectives, a concept map, content organization, interface, navigation, interactive activities, and assessment instruments were prepared. During Development, the digital worksheet was programmed and integrated with multimedia features using HTML, CSS, and JavaScript, followed by expert validation and revision. During Implementation, the revised product was used in a limited classroom trial with 15 students over two meetings. During Evaluation, validation, practicality, implementation, and pretest-posttest findings were reviewed to produce the revised product.

Table 1. Summary of the ADDIE Procedure

Stage	Main Activities	Output
Analysis	Curriculum, learner needs, learner characteristics, material, and facility analysis	Development requirements.
Design	Learning objectives, concept map, content structure, interface, navigation, activities, and assessments	Initial design and storyboard.
Development	HTML, CSS, and JavaScript development; multimedia integration; expert validation and revision	Validated prototype.
Implementation	Limited trial with 15 Grade XI students; observations, teacher/student responses, pretest and posttest	Practicality and preliminary learning data.
Evaluation	Review of validation, practicality, implementation, and learning improvement	Revised final product.

Data analysis

Validation, practicality, and learning implementation data were converted into percentages and interpreted according to the predetermined criteria. Validity was interpreted using the 81–100% very valid category reported by [Ma'aniyah & Mintohari \(2019\)](#). Practicality scores of 80.1–100% were interpreted as very practical following [Arikunto \(2011\)](#), while learning implementation scores of 75–100% were interpreted as very good ([Ahied & Rosidi, 2020](#)). Qualitative needs-analysis data from observations and teacher interviews were summarized descriptively by grouping recurring findings related to instructional problems, learner characteristics, curriculum demands, material characteristics, and technological facilities.

For conceptual understanding, mean, standard deviation, and change in scores were calculated. Because the pretest-posttest design involved the same students, the normality of the difference scores was checked using the Shapiro-Wilk test, followed by a paired-samples t-test and Cohen's d effect size. Learning improvement was also described using the normalized gain (N-Gain) formula, with $g > 0.70$ classified as high, $0.30 \leq g \leq 0.70$ as moderate, and $g < 0.30$ as low refers to [Ramdhani et al., \(2020\)](#).

Equations

The percentage score was calculated using equation on formula 1, refers to [\(Ma'aniyah & Mintohari, 2019\)](#):

$$P = \frac{\sum X}{\sum x_{max}} \times 100\% \dots\dots\dots (1)$$

Where: P is the percentage score, $\sum X$ is the total score obtained, and $\sum X_{max}$ is the maximum possible score.

The improvement in students' conceptual understanding was determined using the Normalized Gain (N-Gain) shown in equation on formula 2, refers to [Ramdhani et al., \(2020\)](#):

$$g = \frac{S_{post} - S_{pre}}{100 - S_{pre}} \dots\dots\dots (2)$$

where: g is the normalized gain, S_{post} is the posttest score, and S_{pre} is the pretest score

RESULT AND DISCUSSION

Needs Analysis

The analysis stage was conducted to identify instructional problems, curriculum requirements, student characteristics, learning material requirements, and the availability of technological facilities. Data were obtained through classroom observations, interviews with the biology teacher, curriculum analysis, analysis of student characteristics, material analysis, and evaluation of the available learning facilities. A comprehensive needs assessment according to [Maylani et al., \(2026\)](#) is considered an essential initial stage in digital worksheet development because it ensures that the learning media are aligned with curriculum demands, students' characteristics, and technological readiness in schools.

Classroom observations and the teacher interview indicated that biology instruction at SMA Wira Bhakti Integrated High School was predominantly conducted through lectures, textbooks, and printed student worksheets. Although these resources were useful for presenting factual and theoretical information, they provided limited support for visualizing the microscopic and interconnected processes involved in photosynthesis. The teacher reported that students frequently experienced difficulty in relating chloroplast structure to the light-dependent reactions, the *Calvin* cycle, and environmental factors affecting the rate of photosynthesis. As a result,

students tended to memorize the stages of photosynthesis without fully understanding the relationships among the underlying concepts.

Curriculum analysis showed that students were expected not only to describe the process of photosynthesis but also to analyze factors affecting photosynthesis, interpret scientific evidence, and explain the relationship between photosynthesis, plant metabolism, and ecosystem sustainability. These competencies require learning activities that promote higher-order thinking, scientific reasoning, and conceptual understanding rather than factual recall. [Buhera et al., \(2025\)](#) stated that interactive digital technologies can support inquiry-based learning by enabling students to visualize abstract scientific phenomena and examine relationships among scientific variables.

Analysis of student characteristics indicated that most students were familiar with smartphones, computers, and internet-based learning platforms. Students also expressed greater interest in learning environments that combined animations, videos, simulations, interactive quizzes, and digital activities than in conventional printed worksheets. This finding is consistent with [Ayuni et al., \(2025\)](#), who reported that interactive E-LKPD can increase students' participation, learning motivation, and independence by providing varied and engaging digital learning experiences.

The analysis also showed that the school had technological facilities that could support the implementation of web-based learning media. However, the availability of digital devices alone was not sufficient to improve learning unless the technology was integrated with appropriate learning objectives, content organization, and instructional activities. [Indah et al., \(2025\)](#) emphasized that the development of digital worksheets should be based on a comprehensive analysis of curriculum demands, student characteristics, technological readiness, and existing instructional problems.

Based on these findings, a coding-based interactive E-LKPD was considered necessary to support the visualization and exploration of photosynthesis. The product was designed to integrate textual explanations, illustrations, animations, instructional videos, simulations, interactive exercises, and assessments within a web-based learning environment. The use of programmed interactive features was intended to allow students to engage directly with the learning content rather than merely read or observe static information. [Astuti & Astuti \(2025\)](#) similarly reported that coding-supported digital learning media can promote interaction, visualization, and active participation in biology learning. Therefore, the needs analysis provided the basis for developing an E-LKPD that was aligned with curriculum objectives, student characteristics, instructional problems, and the technological conditions of the school.

Design and Characteristics of the Developed Digital Worksheet

Based on the results of the needs analysis, an initial prototype of the coding-based interactive digital worksheet was designed using the ADDIE development model. The product was developed as a web-based learning medium integrating text, images, animations, videos, simulations, interactive activities, quizzes, and evaluation tasks into a single interface.

The design process included formulating learning objectives, preparing a concept map, organizing the photosynthesis content, designing the user interface,

developing a navigation system, preparing interactive activities, and constructing assessment instruments. The learning material was organized sequentially, beginning with chloroplast structure, followed by photosynthetic pigments, light-dependent reactions, the Calvin cycle, and environmental factors affecting photosynthesis.

The user interface was designed to be simple, consistent, and accessible so that students could independently navigate each learning component. Navigation buttons, instructions, content menus, multimedia features, and assessment sections were arranged systematically to minimize difficulties during use. The product also provided interactive activities that encouraged students to observe, interpret, compare, and respond to information presented through digital media.

The coding component was used to support the integration of interactive features into the web-based digital worksheet. These programmed features allowed students to access multimedia content, complete interactive exercises, and obtain responses or feedback from the system. Consequently, students were not positioned merely as passive recipients of information but were encouraged to interact with learning content throughout the lesson. Figure 1 presents the homepage of the developed digital worksheet. The homepage provides access to learning objectives, instructions, learning materials, interactive activities, and evaluation components.



Figure 1. Homepage of the Coding-Based Interactive Digital Worksheet

Figure 2 presents examples of the interactive learning features included in the product. These features were designed to support students in visualizing the stages of photosynthesis and relating biological processes to environmental factors. The integration of multimedia and programmed interaction reflects current developments in digital education. [Astuti & Astuti \(2025\)](#) found that coding-supported digital media can increase students' engagement, creativity, and higher-order thinking by allowing them to interact with digital content. Similarly, [Ayuni et al., \(2025\)](#) reported that interactive digital worksheet integrating multimedia elements can provide richer learning experiences than conventional printed worksheets. The initial prototype was subsequently evaluated by material and media experts. Revisions were made based on the experts' comments before the product was implemented in the limited field trial.



Figure 2. Interactive Learning Features of the Developed Digital Worksheet

Validity of the Developed Digital Worksheet

The coding-based interactive digital worksheet was evaluated by one material expert and one media expert before classroom implementation. The validation process examined the appropriateness of the product in terms of content, instructional organization, language, presentation, interface design, navigation, multimedia integration, and technical quality.

Table 2. Expert Validation Results

Expert / Aspect	Items	Score (Obtained/Max)	Percentage	Category
Material — Content feasibility	4	17 / 20	85.00%	Very Valid
Material — Material presentation	4	17 / 20	85.00%	Very Valid
Material — Conceptual understanding	3	12 / 15	80.00%	Valid
Material — Language	3	13 / 15	86.67%	Very Valid
Material — Total	14	59 / 70	84.29%	Very Valid
Media — Product suitability	5	22 / 25	88.00%	Very Valid
Media — Presentation	6	26 / 30	86.67%	Very Valid
Media — Conceptual understanding	3	13 / 15	86.67%	Very Valid
Media — Language	4	13 / 15	86.67%	Very Valid
Media — Total	18	79 / 90	87.78%	Very Valid

The digital worksheet was validated by one material expert and one media expert before classroom implementation. The material expert assessed 14 items covering content feasibility, material presentation, conceptual-understanding alignment, and language. The overall score was 59 of 70 (84.29%), categorized as very

valid. The conceptual-understanding aspect obtained 80.00%, which was categorized as valid, while the other material aspects were categorized as very valid.

The media expert assessed 18 items covering product suitability, presentation, conceptual-understanding support, and language. The overall score was 79 of 90 (87.78%), categorized as very valid. The highest media aspect was product suitability at 88.00%, while the other aspects each obtained 86.67%. Expert suggestions focused on improving the clarity of explanations, correcting typographical errors and scientific terminology, and strengthening the consistency of interface and navigation elements. Revisions were made before the limited field trial. These findings indicate that the digital worksheet met the expert-assessed feasibility criteria used in this study. The results should be interpreted as evidence of product feasibility rather than direct evidence of learning effectiveness. This distinction is important because learning improvement was examined later in a small one-group trial

The findings are consistent with [Evanti & Mawartiningsih \(2025\)](#), who reported that an interactive digital worksheet developed using a Problem-Based Learning approach achieved a very valid category based on content, language, presentation, and media-design assessments. [Bimayu et al., \(2025\)](#) also reported a validity score of 93.14% for a Discovery Learning-based interactive digital worksheet. Their study emphasized that content feasibility, didactic quality, language, and graphical presentation are essential components of a high-quality digital worksheet. Accordingly, the validation results indicate that the developed digital worksheet met the content and media feasibility criteria used in this study. However, the validity findings should be interpreted as evidence of expert-assessed feasibility rather than direct evidence of learning effectiveness.

Similar findings have been reported [Kartikaningtyas & Kuswanti \(2026\)](#) in guided inquiry-based digital worksheet development, where expert validation confirmed that scientifically accurate content, appropriate learning design, and interactive presentation contribute substantially to the overall quality of digital worksheets.

Practicality of the Developed E-LKPD

The practicality of the developed digital worksheet was evaluated during a limited field trial involving 15 eleventh-grade students. The evaluation was based on observations of learning implementation, the biology teacher's response, and students' responses. These aspects were examined to determine whether the digital worksheet could be implemented as planned and whether it was considered accessible and easy to use.

Table 3. Practicality Results of the Digital Worksheet

Assessment Aspect	Participants / Unit	Percentage	Category
Learning implementation	2 meetings	96.18%	Very Good
Teacher response	1 biology teacher; 24 items	97.92%	Very Practical
Student response	15 students; 25 items each	94.88%	Very Practical

Practicality was evaluated during the two-meeting limited field trial involving 15 Grade XI students and one biology teacher. Learning implementation was observed during each meeting, while the teacher and students completed response questionnaires after using the product. The learning implementation score was 96.18%, categorized as very good. The teacher response score was 97.92%, indicating that the product was easy to operate, visually appropriate, and useful for presenting abstract photosynthesis concepts. The teacher response instrument contained 24 items across five aspects: interest, ease of use, material suitability, support for conceptual understanding, and language/presentation.

The student response score was 94.88%, categorized as very practical. The student questionnaire contained 25 items addressing interest, ease of use, material and presentation, learning benefits, and language/visual presentation. The high response score indicates positive perceptions of the digital worksheet's accessibility, navigation, multimedia, and interactive activities. However, these response scores describe perceived practicality and should not be interpreted alone as evidence of learning effectiveness.

These findings are consistent with [Nurfadillah et al., \(2025\)](#), who reported that coding-integrated learning media achieved a very practical category because interactive features, multimedia visualization, and structured activities supported student participation. [Rahmawati et al., \(2025\)](#) similarly found that interactive digital worksheet was considered practical by teachers and students because it facilitated independent learning and provided immediate interaction with learning content.

Overall, the practicality results indicate that the digital worksheet was feasible to use during the limited field trial. However, the high response scores primarily reflect users' perceptions of ease of use, attractiveness, accessibility, and instructional usefulness. They should not be interpreted independently as evidence of high learning effectiveness.

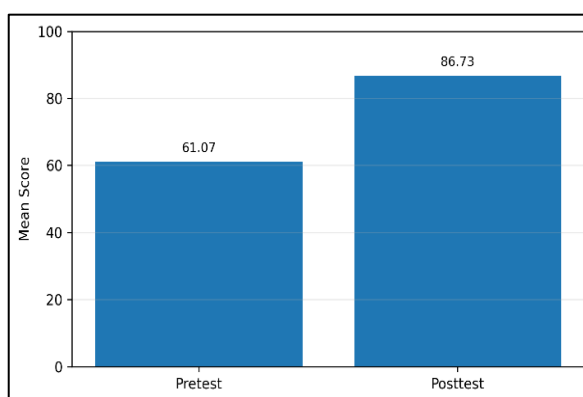


Figure 3. Comparison of Mean Pretest and Posttest Scores

Improvement in Students' Conceptual Understanding

One of the objectives of this study was to examine the improvement in students' conceptual understanding after using the code-enhanced interactive digital worksheet. Conceptual understanding was measured using a pretest administered before implementation and a posttest administered after implementation. The mean

pretest score was 61.07, whereas the mean posttest score increased to 86.73 (Figure 3). Thus, the mean score increased by 25.66 points after students participated in learning using the developed digital worksheet. Based on the individual score records, all 15 students obtained higher posttest scores than pretest scores.

Table 4. Pretest-Posttest Conceptual Understanding Results

n	Pretest Mean ± SD	Posttest Mean ± SD	Paired t (p); Cohen's dz	N-Gain
15	61.07 ± 7.01	86.73 ± 7.66	t(14) = 10.67, p < .001; dz = 2.75	0.66 (Moderate)

The normalized gain analysis produced an average N-Gain score of 0.66, which was classified as moderate. This result indicates that the developed digital worksheet produced a moderate improvement in students' conceptual understanding during the limited field trial. Although the N-Gain did not reach the high category, the increase in mean scores suggests that students developed a better understanding of the concepts assessed after the learning activities.

The observed improvement may be associated with the integration of several instructional features within the digital worksheet. Animations and videos provided visual representations of processes that cannot be directly observed, while interactive activities encouraged students to connect chloroplast structure, light-dependent reactions, the Calvin cycle, and factors affecting photosynthesis. The availability of quizzes and formative activities also provided opportunities for students to review their understanding during the learning process.

The digital worksheet differed from conventional printed worksheets because students were required to interact with multimedia content rather than merely read textual explanations. This interaction may have helped students relate prior knowledge to newly presented information and organize the stages of photosynthesis into a more coherent conceptual framework. However, because this study did not include a control group, the improvement cannot be attributed exclusively to the digital worksheet. Other factors, including teacher guidance, repeated exposure to the material, and familiarity with the test format, may also have contributed to the increased scores.

The findings are consistent with [Suryani et al., \(2025\)](#), who reported that interactive digital worksheet supported students' conceptual understanding by facilitating the visualization of complex biological processes and encouraging students to connect prior knowledge with new concepts. The present findings also support previous studies showing that interactive digital worksheets can provide opportunities for active participation, visualization, and independent exploration.

An important finding of this study is that the practicality scores were very high, whereas the N-Gain remained in the moderate category. This difference indicates that a learning medium that is attractive, accessible, and easy to use does not automatically produce a high level of learning improvement. Students may still require teacher guidance, sufficient learning time, repeated practice, and additional activities to fully understand complex processes such as photosynthesis. Therefore, the digital

worksheet should be viewed as a learning support tool rather than a substitute for instructional guidance.

Overall, the results indicate that the developed coding-based interactive E-LKPD met the validity and practicality criteria established in this study and was associated with a moderate improvement in students' conceptual understanding of photosynthesis.

Research Limitations

This study had several limitations. First, the limited field trial involved only 15 Grade XI students from one senior high school, so the findings cannot be generalized to students with different characteristics or school contexts. Second, the study used a one-group pretest-posttest design without a comparison group; therefore, the observed learning improvement cannot be attributed solely to the digital worksheet.

Third, product validity was assessed by one material expert and one media expert, which limits the breadth of expert perspectives. Fourth, implementation depended on compatible devices and internet access. These limitations indicate that the findings provide preliminary evidence of feasibility and learning improvement rather than definitive evidence of causal effectiveness. Future studies should involve larger and more diverse samples, additional validators, longer implementation periods, and experimental or quasi-experimental designs with comparison groups. Quantitative needs-analysis data may also be collected in future work to complement the qualitative findings used in this study.

CONCLUSION

This study developed a code-enhanced interactive digital worksheet on photosynthesis using the ADDIE model. Expert validation yielded scores of 84.29% for material and 87.78% for media, both categorized as very valid. Practicality was also high, with learning implementation at 96.18%, teacher response at 97.92%, and student response at 94.88%. Students' conceptual understanding increased from a mean pretest score of 61.07 to a mean posttest score of 86.73. The paired-samples t-test indicated a statistically significant within-group increase, $t(14) = 10.67$, $p < .001$, with Cohen's $d_z = 2.75$, while the N-Gain of 0.66 was in the moderate category. These findings provide preliminary evidence that the digital worksheet is feasible and practical and may support conceptual understanding of photosynthesis in a limited classroom trial. The specific contribution of this study is the integration of programmed web-based interaction with animations, simulations, videos, quizzes, and learning activities in a single digital worksheet designed for an abstract biology topic. Because the study was limited to one small group without a control condition, larger and controlled studies are needed to establish generalizability and causal effectiveness.

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