

Development of Process-Image-Based Chemistry Worksheets for Learning Colligative Properties of Solutions

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ABSTRACT

This educational research and development study developed a process-image-based chemistry worksheet for senior high school learning on the colligative properties of solutions and examined its validity, practicality, and effectiveness. The worksheet presents sequential images in which each image represents a stage in the change of an object, event, or phenomenon, enabling students to analyze chemical processes through visual evidence. The study involved Grade XII MIPA 4 students at SMA Negeri 1 Bangorejo. A limited trial involved 10 students, followed by a class trial involving 34 students using a one-group pretest–posttest design. Product validity was evaluated through expert judgment by three validators, practicality through student responses and classroom implementation, and effectiveness through conceptual-understanding tests, normalized gain, classical mastery, and a retention test administered three weeks after the posttest. The worksheet obtained an overall validation mean of 4.05 and was categorized as valid. Student responses were positive across both trials, while classroom implementation reached 76.36% in the third topic. The mean conceptual-understanding score increased from 44.28 on the pretest to 79.01 on the posttest, with a mean N-gain of 0.58 (moderate). Classical mastery reached 85.29%. The retest mean was 77.96, indicating strong retention, although mastery declined slightly to 82.35%. These findings support the feasibility of process-image worksheets as a visual scaffold for colligative-properties learning; however, causal claims remain limited by the single-group design and the small, single-school sample.

Keywords: chemistry worksheet; process images; colligative properties; visual representation; conceptual understanding

INTRODUCTION

Chemistry learning requires students to coordinate observable phenomena, particulate-level explanations, and symbolic representations. This representational demand is especially important for topics such as colligative properties, where macroscopic changes in boiling point, freezing point, vapor pressure, and osmotic behavior must be connected with particle-level interpretations and mathematical relationships. Research in chemistry education has long identified the difficulty of moving productively among representational levels, and contemporary work continues to emphasize representational competence as a core component of meaningful chemistry learning (Johnstone, 2000; Talanquer, 2018; Taber, 2019; Rau, 2020).

The source study was motivated by a classroom problem: chemistry learning tended to remain theoretical and mathematical, while students had limited opportunities to examine the processes underlying chemical phenomena. The proposed response was a student worksheet (LKS) organized around process images—sequential visual representations intended to make stages of change available for observation, comparison, analysis, and discussion. Such a design is consistent with evidence that visual and multiple representations can support learning when they direct attention to relevant relationships and are integrated with explanatory activity rather than presented as decoration (Mayer et al., 2020; Castro-Alonso et al., 2021; Noetel et al., 2022; Fiorella, 2023).

Worksheets can also support student-centered learning by structuring tasks, prompts, and evidence without requiring the teacher to provide every explanation directly. Active-learning research indicates that students benefit when they retrieve, generate, explain, compare, and receive feedback on ideas (Theobald et al., 2020; Agarwal et al., 2021; Brod, 2021; Carpenter et al., 2022). In chemistry, carefully designed visual prompts may help learners externalize relationships that are otherwise difficult to infer from equations alone.

This study therefore addresses three questions: (1) Is the process-image-based chemistry worksheet valid according to expert judgment? (2) Is it practical based on student responses and observed implementation? and (3) Is it effective descriptively based on conceptual-understanding gain, classical mastery, and retention? The article reports the original development data while interpreting the one-group pretest–posttest evidence cautiously.

LITERATURE REVIEW

Visual Representation and Chemistry Learning

Visual representation is central to chemistry because many target entities and mechanisms are not directly observable. Learners must coordinate diagrams, particle models, graphs, equations, and verbal explanations. Multiple-representation research shows that visualizations can facilitate integration and inference, but only when learners understand what each representation encodes and how representations relate to one another (Rau, 2020; Castro-Alonso et al., 2021). Cognitive load theory likewise predicts that instructional visuals are beneficial when they reduce unnecessary processing and highlight germane relations (Sweller, 2020; Skulmowski, 2024).

Process images differ from a single illustrative picture because they display an ordered sequence. Their pedagogical value lies in making change visible across stages, thereby inviting comparison and causal explanation. Generative-learning perspectives suggest that learners benefit when they select relevant information, organize it, and integrate it with prior knowledge through activities such as explaining, drawing, mapping, or comparing (Fiorella, 2023; Brod, 2021). For colligative properties, sequential images can be used to connect solution composition with observable changes and symbolic calculations.

Student Worksheets and Student-Centered Learning

A worksheet is not inherently student-centered; its value depends on the cognitive activity it elicits. Effective task design should provide sufficient guidance while requiring learners to make decisions, articulate reasoning, and connect evidence with concepts. Research on active learning, feedback, and retrieval practice supports structured participation over passive reception (Wisniewski et al., 2020; Theobald et al., 2020; Agarwal et al., 2021; McDermott, 2021). In this study, the worksheet was intended to function as a scaffold for individual and group analysis of process images.

Visual worksheets can also be understood through multimedia-learning principles. Coherent combinations of words and pictures may support comprehension, whereas redundant or poorly aligned elements can create extraneous cognitive load (Sundararajan & Adesope, 2020; Mayer et al., 2020; Noetel et al., 2022). The clarity of each image, the sequencing of prompts, and the alignment between visual evidence and the target concept are therefore important aspects of product validity and usability.

Validity, Practicality, Effectiveness, and Retention

Educational product development commonly evaluates whether a resource is defensible in content and design, usable in its intended setting, and associated with desired learning outcomes. In the present study, validity was judged by experts, practicality was represented by student responses and implementation observations, and effectiveness was represented by pretest–posttest change, normalized gain, mastery, and delayed retention. A one-group design can describe change but cannot rule out testing, maturation, history, teacher effects, or other alternative explanations. Consequently, normalized gain and retention are treated as descriptive indicators rather than causal effect estimates (Hake, 2002; Lakens, 2022).

METHODS

Research Design, Setting, and Participants

The study used educational research and development to produce a process-image-based chemistry worksheet on the colligative properties of solutions. The development sequence comprised three broad stages adapted from the source study: preliminary study, design, and development. The preliminary stage included classroom observation, literature/document analysis, learner-characteristic analysis, and analysis of the curriculum content. The design stage produced the initial worksheet draft, and the development stage involved expert validation, revision, a limited trial, further revision, and a class-scale trial.

The research was conducted with Grade XII MIPA 4 students at SMA Negeri 1 Bangorejo, Banyuwangi. Trial I involved 10 students. Trial II involved 34 students during the first semester of the 2019/2020 academic year. The class trial used a one-group pretest–posttest design (O1–X–O2), where O1 was the conceptual-understanding pretest, X was learning with the process-image worksheet, and O2 was

the posttest. A retention test was administered three weeks after the posttest using the same items with reordered questions and response options.

Table 1. Study phases and evidence used to evaluate the worksheet

Phase	Participants / evidence	Purpose
Expert validation	Three validators	Content, presentation, language, and graphic feasibility
Trial I	10 Grade XII students	Initial usability and student response
Trial II	34 Grade XII students	Practicality and conceptual-understanding outcomes
Retention	34 Grade XII students	Delayed conceptual retention three weeks later

Measures and Analysis

Product validity was assessed by three validators: a science-education expert, a graphic-design expert, and a chemistry teacher. Four dimensions were evaluated: content feasibility, presentation, language, and graphic feasibility. Practicality was assessed using student-response questionnaires and observations of classroom implementation across three topics. Effectiveness was described using conceptual-understanding pretest and posttest scores, normalized gain (N-gain), classical mastery, and delayed retention. The source study classified N-gain values of 0.30–0.70 as moderate. Because participant-level scores and variance estimates were not available in the manuscript, no paired inferential test, confidence interval, or standardized effect size was reconstructed.

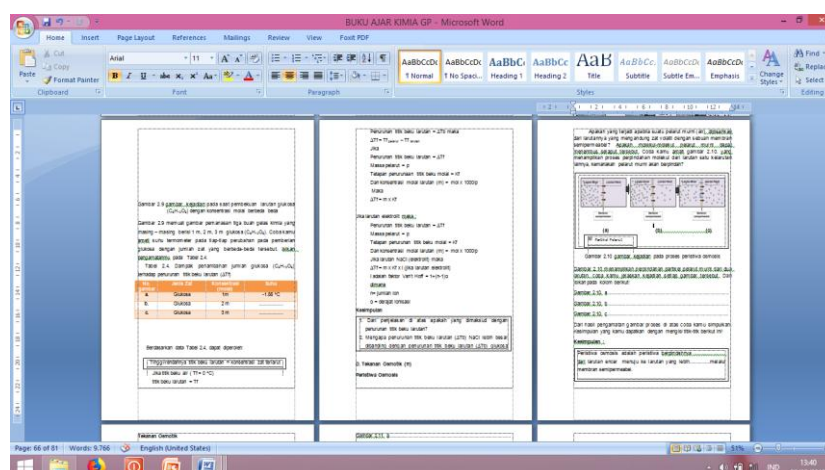


Figure 1. Original development design for the process-image-based chemistry worksheet

RESULTS AND DISCUSSION

Product Validity

The expert-validation results indicate that the first worksheet draft met the study's validity criterion. The overall mean across validators was 4.05. Language obtained the highest dimension mean (4.17), followed by content feasibility (4.15), graphic feasibility (4.00), and presentation (3.88). These results

suggest that the worksheet was considered suitable in content and form before classroom implementation, while the comparatively lower presentation score identifies an area where sequencing and visual organization may warrant particular attention.

Table 2. Validation results for the process-image-based chemistry worksheet

Assessment aspect	Validator 1	Validator 2	Validator 3	Mean	Criterion
Content feasibility	4.20	3.80	4.20	4.15	Valid
Presentation	4.13	3.88	3.75	3.88	Valid
Language	4.00	4.00	4.33	4.17	Valid
Graphic feasibility	4.00	4.00	4.00	4.00	Valid
Overall	4.08	3.92	4.07	4.05	Valid

The validation pattern is consistent with multimedia-learning principles: the instructional value of pictures depends on their relevance, legibility, spatial organization, and relationship with accompanying prompts (Mayer et al., 2020; Castro-Alonso et al., 2021; Noetel et al., 2022). The original trial notes also show that some students found several images unclear, reinforcing the importance of visual quality rather than merely increasing the number of illustrations.

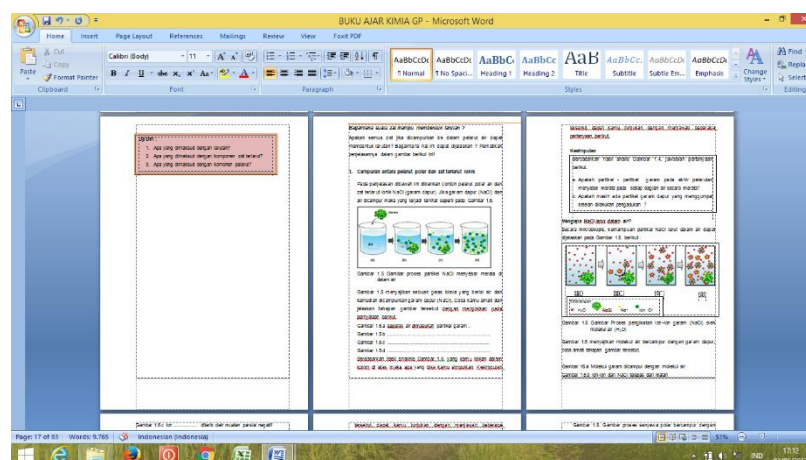


Figure 2. Example of the process-image-based chemistry worksheet retained from the source manuscript

Practicality: Student Responses and Classroom Implementation

During Trial I, student responses were generally positive, although feedback indicated that some images required revision for clarity. After revision, Trial II responses remained in the “good” range across the three topics, with mean response scores of 3.72, 3.74, and 3.78. The implementation observation also showed generally sustained participation. The reported implementation percentages were 74.55%, 74.55%,

and 76.36% across Topics 1–3, respectively. These observations support practical classroom use but should be interpreted as implementation evidence rather than direct evidence of learning.

Table 3. Student responses in Trial II

Response category	Topic 1	Topic 2	Topic 3
Very good	2	3	3
Good	28	26	26
Fairly good	4	5	5
Poor	0	0	0
Very poor	0	0	0
Mean response score	3.72	3.74	3.78

The positive response pattern is pedagogically plausible because process images can make an abstract topic more inspectable and can provide common visual evidence for group discussion. However, engagement and liking should not be equated with conceptual learning. Reviews of instructional media consistently distinguish motivational or engagement outcomes from achievement outcomes and emphasize the role of task structure, guidance, and feedback (Darling-Hammond et al., 2020; Bond et al., 2020; Wisniewski et al., 2020; Skulmowski, 2024).

Conceptual Understanding, N-Gain, and Retention

The mean conceptual-understanding score increased from 44.28 on the pretest to 79.01 on the posttest, a descriptive increase of 34.73 points. The source study reported a mean normalized gain of 0.58, classified as moderate. Twenty-nine of 34 students achieved the minimum mastery criterion on the posttest, corresponding to 85.29% classical mastery. Three weeks later, the mean retest score was 77.96; 28 students met the mastery criterion, corresponding to 82.35%. Thus, the mean score declined by 1.05 points and mastery declined by 2.94 percentage points between posttest and retest.

Table 4. Pretest, posttest, and retest summary in Trial II

Indicator	Pretest	Posttest	Retest
Mean	44.28	79.01	77.96
Highest score	65.00	88.00	88.00
Lowest score	45.00	67.00	65.00
Students $\geq$ mastery criterion	0	29	28
Students $<$ mastery criterion	34	5	6
Classical mastery (%)	0	85.29	82.35

The increase is consistent with theories of generative and active learning: students who must inspect a sequence, compare states, infer relationships, and explain conclusions engage in more constructive

processing than students who only receive finished explanations (Fiorella, 2023; Brod, 2021; Theobald et al., 2020). The near-maintenance of the mean score after three weeks is also compatible with evidence that retrieval and elaborative processing can support retention (Agarwal et al., 2021; Carpenter et al., 2022; McDermott, 2021). Nevertheless, the design does not establish that the worksheet alone caused the observed improvement because there was no comparison group or random assignment.

Limitations

The study has several limitations. It involved one class in one school, with only 10 students in the limited trial and 34 in the class trial. The one-group pretest–posttest design is vulnerable to testing, maturation, history, and teacher-related effects. The manuscript does not provide participant-level scores, reliability coefficients for the tests and response questionnaire, detailed item-validity evidence, or uncertainty estimates. In addition, the source reports a retention value of 98.67 in the abstract but 99.42 in the results narrative; because the underlying individual data are unavailable, this inconsistency cannot be independently resolved. Future studies should use validated measures, report reliability and item analysis, include a comparison condition, and provide participant-level descriptive statistics and inferential estimates.

CONCLUSION AND RECOMMENDATIONS

The process-image-based chemistry worksheet for colligative properties was rated valid by three validators, with an overall mean validation score of 4.05. Classroom evidence also indicated positive student responses and feasible implementation. In the 34-student class trial, the mean conceptual-understanding score increased from 44.28 to 79.01, the reported mean N-gain was 0.58, and posttest classical mastery reached 85.29%. The mean retest score three weeks later was 77.96, with 82.35% mastery. These findings support the worksheet as a feasible visual scaffold for senior high school chemistry, but they should be interpreted descriptively rather than as proof of causal effectiveness. Future development should improve image clarity, extend process-image worksheets to other chemistry topics where sequential change is conceptually important, and test the materials with larger multi-school samples and stronger comparison designs.

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