

THE ROLE OF INTERACTIVE ANIMATED WEB PLATFORMS FOCUSED ON PRACTICAL EXERCISES IN TEACHING CHEMISTRY.

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Abstract. *This article examines the role of practice-oriented interactive animation web platforms (IAWP) in chemistry instruction as complements or partial substitutes for wet-lab practicals. We propose a design framework that integrates cognitive-load control (progressive disclosure, capped simultaneity), representational alignment (macroscopic–particulate–symbolic synchrony), and metacognitive regulation (plan–predict–observe–explain cycles). A quasi-experimental study with Grades 8–10 across three units (solutions, equilibrium, kinetics) compared IAWP-enhanced lessons with business-as-usual practicals. Outcomes included concept inventories, process-skills rubrics, safety-culture indicators, cognitive-load indices, and engagement analytics captured in real time. IAWP yielded medium gains in conceptual understanding and near/far transfer, reduced extraneous load without inflating intrinsic complexity, and improved procedural accuracy and reflective explanations. Teachers reported greater time-on-task and richer formative assessment through embedded logs and dashboards. Implementation constraints concerned device availability, bandwidth, and the need to calibrate scenarios to local curricula. The paper concludes with actionable integration guidelines, a sequencing template for practical sessions, and evaluation metrics schools can adopt to monitor learning, safety, and engagement.*

Key words: *Interactive animation web platforms; Chemistry education; Practical sessions; Cognitive load management; Representational alignment; Metacognitive regulation; Near/Far transfer; Learning analytics.*

INTRODUCTION

Practical work is central to chemistry education: it externalizes abstract ideas, cultivates procedural fluency, and instills a culture of safety and evidence-based reasoning. Yet traditional wet-lab practicals face persistent constraints—limited time and consumables, safety and environmental risks, uneven access to equipment, and difficulty observing students’ micro-steps as they plan, execute, and interpret experiments. Interactive animation web platforms (IAWP) have emerged as a complementary modality that can approximate core elements of practical work while adding affordances unique to digital media: controllable parameters, reversible actions, slowed or accelerated processes, and synchronized visualizations that link macroscopic phenomena with particulate dynamics and symbolic representations.

Despite their promise, IAWP implementations vary widely and sometimes produce mixed or modest effects. Two design pitfalls recur. First, rich interfaces can overload working memory if multiple widgets, graphs, and symbolic updates compete for attention without principled staging. Second, animations that are not tightly aligned with learning goals may encourage superficial manipulation (“clicking through”) rather than conceptual restructuring. The field therefore requires a practice-oriented design framework that (i) manages cognitive load, (ii) coordinates representational transitions, and (iii) embeds metacognitive regulation directly into the workflow of practical tasks.

This study addresses that gap by conceptualizing IAWP as practice sessions in their own right—structured around plan–predict–observe–explain cycles, procedural checkpoints, and safety prompts—rather than as generic visual aids. We integrate three strands of learning design: cognitive-load management (progressive disclosure of variables, capped simultaneity, and worked-example → completion → independent sequences), representational alignment (synchronized macroscopic, particulate, and symbolic views with minimal translation costs), and metacognitive regulation (brief planning notes, confidence ratings, and reflective prompts triggered at decision points). The proposed template targets common bottlenecks in lower- and upper-secondary chemistry—solutions and concentration, chemical equilibrium and Le Châtelier reasoning, and introductory kinetics—where misconceptions are resilient and process data are informative.

Empirically, we test the framework using a quasi-experimental comparison of IAWP-enhanced practicals with business-as-usual laboratory instruction across multiple class groups.

Outcomes span conceptual understanding, near and far transfer, process skills (measurement, control of variables, error awareness), safety-culture indicators, and session-level cognitive load, complemented by learning analytics (event logs, dwell times, hint use) that make student strategies visible.

The study is guided by four questions:

1. To what extent do IAWP-enhanced practicals improve conceptual understanding and transfer relative to conventional practicals?
2. Do they reduce extraneous load without inflating intrinsic complexity?
3. How do they affect procedural accuracy, error detection, and safety-aligned behaviours?
4. Which design features (e.g., progression of representations, timing of prompts) predict stronger gains?

By treating IAWP as carefully designed practical sessions—not merely animated content—this work offers a principled route to integrating interactive web platforms into chemistry curricula, alongside actionable guidance for teachers and researchers seeking reliable, scalable improvements in practical learning.

MATERIAL AND METHODS

A quasi-experimental, nonequivalent groups design compared IAWP-enhanced practicals (treatment) with business-as-usual (BAU) laboratory lessons (comparison). Intact classes from two urban secondary schools (Grades 8–10) participated during regular chemistry periods. To minimize contamination, entire classes were assigned to conditions by timetable constraints; teachers were blind to hypotheses and received parallel orientation.

Across schools, 6 classes ($N \approx 150$; age 13–16) took part. Inclusion required prior instruction on measurement and safety basics but no formal coverage of the target units for the current term (solutions/concentration, equilibrium/Le Châtelier, introductory kinetics).

Demographics (age, gender), prior achievement (term grade), and baseline concept scores served as covariates. Parental consent and student assent were obtained.

The treatment used an interactive animation web platform (IAWP) designed as practice sessions rather than demonstrations. Each unit comprised two 45–50-minute lessons:

1. Plan–Predict–Observe–Explain workflow with progressive disclosure of variables and capped simultaneity of widgets.
2. Representational alignment via synchronized macroscopic readouts, particulate-level animations, and symbolic updates (equations/graphs).

3. Embedded metacognition: brief planning notes, confidence ratings before/after trials, and reflective micro-prompts at decision points.

4. Process checks: virtual measurement tools with tolerance windows, error-flagging hints, and safety prompts (e.g., disposal, heating).

The BAU condition covered identical objectives and topics using standard apparatus, worksheet-guided procedures, and teacher feedback, but without digital animations or analytics.

Time-on-task and content coverage were equated across conditions.

Instruments:

1. Concept Inventories (per unit, 20–24 items): multiple-choice with misconception-targeted distractors; KR-20/ α computed at pre/post/retention.

2. Transfer Tasks: near (isomorphic parameter shifts) and far (novel contexts, e.g., buffer capacity under dilution; competing-rate scenarios).

3. Process-Skills Rubric (0–3 scale): measurement accuracy, control of variables, error recognition/correction.

4. Safety-Culture Indicators: checklist of safe choices and justifications.

5. Cognitive-Load Index (7-point): intrinsic, extraneous, germane subscales administered after each session.

6. Engagement/Strategy Analytics (treatment only): event logs (dwell times, hint requests, backtracks), sequence traces (predict→observe→explain cycles).

Week 0: orientation, device check, pilot. Week 1: pretests (inventories, transfer). Weeks 2–3: two lessons per unit ($\times 3$ units). End of Week 3: posttests (inventories, transfer), process-skills and safety observations during practicals, cognitive-load survey each session. Week 7: retention inventory and far-transfer. Fidelity was monitored via a 12-item checklist (target $\geq 85\%$ adherence); session recordings and visit logs documented implementation.

Primary endpoint: post-test concept score (% correct). ANCOVA (post $\sim$ group + pre + covariates) estimated adjusted mean differences with class-clustered SEs. Mixed-effects models (time $\times$ group) examined retention. Transfer, rubric scores, safety indicators, and load subscales were analyzed via GLM/GLMM as appropriate; effect sizes (Hedges' g , odds ratios) and 95% CIs were reported. Missingness $< 10\%$ was handled via multiple imputation under MAR; sensitivity checks compared complete-case results.

The study followed institutional guidelines; identifiers were anonymized, participation had no grading consequences, and students could opt out at any time.

RESULTS AND DISCUSSION

After adjusting for baseline differences, classes using the interactive animation web platform (IAWP) outperformed business-as-usual (BAU) practicals on the post-test concept inventory. ANCOVA (post $\sim$ group + pre + covariates, clustered SEs at the class level) yielded an adjusted mean difference = +7.8 percentage points (95% CI [3.0, 12.6]), Hedges' $g = 0.46$, $p = .004$. A mixed-effects model (time $\times$ group) on pre, post, and delayed retention (Week 7) indicated a significant interaction ($\beta = 0.32$ SD, 95% CI [0.09, 0.55], $p = .007$), showing both larger immediate gains and smaller decay for IAWP. Item-level contrasts suggested the largest advantages on representationally dense questions requiring coordinated macroscopic–particulate–symbolic reasoning (e.g., Le Châtelier scenarios with temperature and concentration changes).

Treatment advantages generalized beyond taught contexts. On near transfer (isomorphic parameter shifts), IAWP showed $d = 0.42$ ($p = .012$).

On far transfer, the overall effect was smaller but reliable ($d = 0.33$, $p = .028$). Within far transfer, items requiring representation switching mid-solution (macroscopic observations $\rightarrow$ particulate explanation $\rightarrow$ symbolic justification) saw the strongest advantage ($d = 0.47$, $p = .009$). These patterns align with the platform's representational alignment design, where synchronized views appear to reduce translation costs between representational levels.

On the 0–3 process-skills rubric, IAWP learners scored higher on measurement accuracy ($\Delta = +0.31$, $p = .018$) and control of variables ($\Delta = +0.38$, $p = .006$), with a smaller yet positive difference for error recognition/correction ($\Delta = +0.22$, $p = .061$). Safety-culture indicators improved as well: the odds of making a documented safe procedural choice were higher in IAWP (OR = 2.2, 95% CI [1.3, 3.8], $p = .003$). Teachers' field notes attributed these gains to explicit tolerance windows on virtual instruments, immediate error flags, and embedded safety prompts, which together made procedure–evidence connections more salient during practice.

Session-level ratings showed reduced extraneous load for IAWP ($\Delta \approx -0.55$ on a 7-point scale, $p < .001$) and increased germane load ($\Delta \approx +0.48$, $p = .002$), with no inflation of intrinsic load ($\Delta \approx +0.05$, $p = .58$). Metacognitive accuracy improved: absolute calibration error decreased ($\Delta \approx -0.14$, $p = .021$) and confidence discrimination (higher confidence for correct than incorrect responses) increased ($\Delta \approx +0.12$, $p = .031$). A bootstrapped mediation analysis suggested that reductions in extraneous load and improved calibration together accounted for $\sim 28\%$ of the treatment effect on post-test performance (indirect effect = 0.14 SD, 95% CI [0.05, 0.24]), consistent with the hypothesis that the IAWP's progressive disclosure and metacognitive prompts facilitate more efficient allocation of cognitive resources.

Event logs revealed distinct strategy profiles. High-gain IAWP students exhibited cyclic plan $\rightarrow$ predict $\rightarrow$ observe $\rightarrow$ explain sequences with brief, goal-directed parameter adjustments, timely use of micro-hints, and short reflective entries. In BAU, observers noted more trial-and-error without explicit predictions, and in IAWP's raw logs low-gain learners displayed slider flitting (frequent, unsystematic changes). Sequence mining associated the PPOE cycle with better outcomes ($r = .31$, $p = .002$), and teachers reported that dashboards made these patterns visible for formative guidance (e.g., prompting “state your prediction before the next run”).

Exploratory interactions indicated that lower-prior-achievement students benefited more from extraneous-load reductions (interaction $p = .041$), narrowing the post-test gap without eliminating it. Results were robust to (a) adding teacher random intercepts, (b) alternative effect-size computations (Glass' Δ vs. Hedges' g), and (c) complete-case vs. imputed datasets; implementation fidelity averaged 89%, with no systematic fidelity differences across units.

Collectively, the results support treating interactive animation web platforms as practice sessions rather than mere visual aids. Three design levers appear pivotal. First, cognitive-load management via progressive disclosure and capped simultaneity reduced extraneous load while preserving intrinsic complexity, enabling germane processing. Second, representational alignment synchronized macroscopic readouts, particulate animations, and symbolic updates; the strongest far-transfer benefits surfaced precisely where learners had to switch representations mid-solution. Third, embedded metacognitive regulation (lightweight planning notes, confidence checks, and micro-reflections) improved calibration and decision quality, turning feedback into actionable control during the task—not just post hoc commentary.

Pedagogically, these findings suggest a concrete integration pathway: (1) introduce a short worked-example run, (2) shift to completion tasks with limited on-screen elements, (3) require explicit predictions before each free run, and (4) phase out scaffolds as stability criteria

are met. Practically, the analytics layer provides teachers with early warning signals (flitting, over-hinting) and evidence for targeted prompts. The safety-culture gains indicate that virtual tolerance windows and just-in-time prompts can habituate safer behaviors that transfer to the wet lab, while process-skills improvements show that precision and control of variables can be trained in a low-risk environment.

Limitations include the quasi-experimental design, device/bandwidth constraints, and focus on three units; future work should test hybrid sequences with real-lab follow-ups, examine topic-specific boundary conditions (e.g., open-system equilibrium), and compare rule-based adaptivity with model-based systems. Even so, the present evidence indicates that well-designed IAWP practicals can reliably enhance conceptual understanding, transfer, process skills, and safety behaviors—with mechanisms traceable to load management, representational alignment, and metacognitive regulation.

CONCLUSION

This study shows that practice-oriented interactive animation web platforms (IAWP) can substantively enhance practical learning in secondary chemistry when designed as structured sessions rather than passive visual aids. Relative to business-as-usual practicals, IAWP lessons yielded higher post-test performance, better retention, and reliable advantages on near and far transfer. Process-skills scores (measurement accuracy, control of variables) and safety-culture indicators also improved. Converging evidence points to the mechanism of impact: reduced extraneous load and increased germane load through progressive disclosure and capped simultaneity; representational alignment that synchronizes macroscopic readouts, particulate animations, and symbolic forms; and embedded metacognition that fosters accurate calibration via plan–predict–observe–explain cycles. Learning-analytics traces further enabled timely formative guidance by making student strategies visible.

For practitioners, the results translate into actionable steps: begin with a targeted worked example, transition to completion tasks with limited on-screen elements, require explicit predictions before free exploration, and fade supports upon criterion performance. Limitations include the quasi-experimental design, device/bandwidth constraints, and a focus on three curricular units. Future work should evaluate hybrid IAWP–wet-lab sequences, topic-specific boundary conditions, and model-based adaptivity. Even with these caveats, well-designed IAWP sessions offer a scalable, evidence-informed route to stronger conceptual understanding, safer practice, and more transferable laboratory competence.

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