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Development of Project-Based Learning Resources Integrated with Virtual Laboratory to Enhance Higher-Order Thinking Skills in HPLC Teaching

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Abstract: *This study aimed to develop project-based learning resources integrated with a virtual laboratory to enhance higher-order thinking skills (HOTS) in teaching High-Performance Liquid Chromatography (HPLC). The research followed the ADDIE model (Analysis, Design, Development, Implementation, Evaluation) and employed a quasi-experimental design with a pretest-posttest control group. Participants were undergraduate chemistry students at Universitas Negeri Medan taking the Separation Chemistry course. The developed resources combined HPLC content, mini-projects, virtual laboratory simulations, and data analysis activities. Expert validation confirmed the resources as feasible to highly feasible. Implementation showed that experimental classes achieved moderate N-Gain scores (0.47–0.55) compared to the control class (0.25, low category). Independent-samples t-tests indicated significant differences in learning outcomes (Sig. 0.000 < 0.05). HOTS scores averaged 74.41 (good category), with analytical thinking highest (79.97), followed by evaluation (73.97) and creative thinking (69.30). Student responses were positive (overall mean 4.07, good category). The integrated resources effectively overcome laboratory limitations, support active learning, and improve both conceptual understanding and HOTS in HPLC instruction.*

Keywords: *project-based learning; virtual laboratory; higher-order thinking skills; HPLC; chemistry education*

INTRODUCTION

Science education at the tertiary level requires approaches that develop not only conceptual mastery but also scientific process skills and higher-order thinking. In the Merdeka Curriculum context and the demands of Society 5.0, chemistry learning must equip students with 21st-century skills, particularly critical thinking, creativity, collaboration, and communication (Alami et al., 2022; Dhini et al., 2024).

High-Performance Liquid Chromatography (HPLC) is a core topic in Separation Chemistry courses. It demands understanding of instrumental principles, parameter optimization, sample preparation, and chromatogram interpretation (Yulina et al., 2022). However, many institutions face limited access to HPLC instruments, high operational costs, and restricted practical time. As a result, instruction often remains theoretical, leaving students with incomplete conceptual and procedural competence (Situmorang et al., 2022).

Project-Based Learning (PjBL) offers opportunities for students to construct knowledge through authentic tasks, thereby fostering active engagement and HOTS (Pakpahan et al., 2022; Juliandini et al., 2020). Virtual laboratories provide safe, repeatable, and accessible alternatives for practical experiences (Nuzula & Jatmiko, 2023; Rokhim et al., 2020). Integrating PjBL with virtual laboratories can address facility constraints while promoting analytical, evaluative, and creative thinking.

Previous studies have shown the benefits of innovative chemistry materials and virtual labs (Situmorang et al., 2018; Sinaga et al., 2019; Pardosi & Situmorang, 2023). However, systematic development of project-based resources specifically integrated with HPLC virtual laboratories and evaluated for HOTS remains limited. This study therefore developed and implemented such resources and examined their effects on learning outcomes and HOTS.

METHODS

Research Design and Participants.

The study employed a Research and Development (R&D) approach using the ADDIE model, followed by a quasi-experimental design (untreated control group with pretest and posttest). Participants were undergraduate Chemistry students at Universitas Negeri Medan enrolled in Separation Chemistry. One control class (n = 30) received conventional instruction, while three experimental classes (n = 30, 23, and 33) used the developed project-based virtual laboratory resources.

Development Procedure.

Analysis stage involved needs analysis through lecturer interviews, student questionnaires, and review of existing materials, which revealed limited interactivity, insufficient practical opportunities, and high demand for project-based and virtual laboratory support. In the Design and Development stages, resources were structured around five subtopics aligned with PjBL stages: (1) Introduction to HPLC, (2) Components and principles, (3) Sample and standard preparation, (4) Virtual HPLC analysis (injection, parameter setting, chromatogram observation), and (5) Data analysis, interpretation, and project reporting. Mini-projects focused on instrument recognition, condition selection, separation, chromatogram interpretation, and quantitative analysis.

Content and media experts evaluated the resources using BSNP-adapted instruments (scale 1–4). Criteria: 3.26–4.00 = highly feasible; 2.51–3.25 = feasible. Experimental classes completed the projects

via the virtual laboratory. Learning outcomes were measured by multiple-choice pretest-posttest (validated and reliable). HOTS was assessed via rubric focusing on analytical, evaluative, and creative thinking during project activities. Student responses were collected via questionnaire (scale 1–5).

Data Analysis.

N-Gain was calculated as (posttest – pretest)/(maximum – pretest). Categories: <0.30 low; 0.30–0.70 moderate; ≥0.70 high. Normality (Shapiro-Wilk), homogeneity (Levene), and independent samples t-tests were performed ($\alpha = 0.05$). HOTS scores were converted to percentages and categorized (60–79% = good). Response data used mean scores (3.41–4.20 = good; ≥4.21 = very good).

RESULTS AND DISCUSSION

Product Development and Feasibility.

Needs analysis confirmed high demand for interactive, project-oriented, and virtual practical resources. The developed virtual laboratory integrated instructional content, guided mini-projects, interactive simulations (weighing, dilution, injection, parameter adjustment, chromatogram generation), calculation tools, and reporting features. Expert validation placed the product in the feasible to highly feasible category across content, presentation, language, and media aspects.

Learning Outcomes.

Table 1 summarizes the N-Gain results. Experimental classes obtained moderate N-Gain (0.47–0.55), while the control class obtained low N-Gain (0.25). Independent samples t-tests showed significant differences between control and each experimental class (Sig. 0.000 < 0.05 for all comparisons). Data met normality and homogeneity assumptions in the majority of cases.

Table 1. Summary of N-Gain Analysis

Class	n	Pretest	Posttest	N-Gain	Category
Control	30	38.33	53.67	0.25	Low
Experiment 1	30	38.33	71.33	0.55	Moderate
Experiment 2	23	38.70	68.70	0.52	Moderate
Experiment 3	33	46.36	69.39	0.47	Moderate

The moderate N-Gain in experimental classes and significant differences versus control demonstrate that project-based virtual laboratory resources enhance HPLC learning outcomes more effectively than conventional instruction. This aligns with prior findings that innovative materials and virtual laboratories improve conceptual mastery and procedural skills when physical instruments are limited (Situmorang et al., 2018; Sinaga et al., 2019; Batubara & Situmorang, 2025; Pardosi & Situmorang, 2023).

Higher-Order Thinking Skills.

Overall HOTS mean score was 74.41 ± 0.39 (good category). Component scores: analytical thinking 79.97 ± 4.02, evaluation thinking 73.97 ± 3.32, and creative thinking 69.30 ± 3.37. Students demonstrated strong ability to identify HPLC components, interpret chromatograms, evaluate data validity, and identify potential errors, while creative solution generation remained the relatively lower (yet still good) aspect.

Integration of PjBL stages with virtual simulations enabled students to move from conceptual understanding through guided exploration to independent data interpretation and reporting. Analytical thinking showed the highest gain because the virtual environment repeatedly required students to examine chromatograms, calculate concentrations, and link parameters to separation quality. Evaluation skills developed through comparison of results with standards and identification of sources of error. Creative thinking, while still in the good range, was comparatively lower, suggesting that future iterations could incorporate more open-ended project variants.

Student Responses.

Across three experimental classes, overall response mean was 4.07 (good). Highest-rated aspect was ease of use (4.21, very good). Other aspects (content feasibility, media attractiveness, HOTS support, engagement, usefulness) ranged 3.96–4.09 (good). Students appreciated accessibility, interactivity, and support for independent analysis.

Positive student responses, particularly regarding ease of use and HOTS support, indicate good acceptance and usability. The resources successfully mitigate common barriers (instrument scarcity, cost, time) while maintaining scientific rigor. Limitations include the moderate (not high) N-Gain levels and the single-institution sample. Broader multi-site trials and expansion of project complexity are recommended.

CONCLUSION

Project-based learning resources integrated with a virtual HPLC laboratory were successfully developed through systematic ADDIE stages and validated as feasible. Implementation significantly improved student learning outcomes (moderate N-Gain vs. low in control) and supported HOTS development (overall good category, strongest in analytical thinking). Students responded positively to the resources. The product offers a practical, scalable solution for HPLC instruction under facility constraints and can be adopted or further refined by chemistry educators.

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