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Original Article

Project-Based Learning with Virtual Laboratories to Promote Higher-Order Thinking Skills to Achieve Competency in Chemical Separation

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ABSTRACT

Background: Higher-order thinking skills become life skills for pharmacists and scientists that are needed in solving scientific problems and can be obtained through implementing appropriate learning models. **Objectives:** The research aims to implement a project-based learning with virtual laboratory to build higher-order thinking skills as a strategy for achieving chemical separation competence. **Materials and Methods:** The study was conducted involving 98 undergraduate students, devided into experimental and control groups. The research stages include developing and standardizing a project-based learning integrated virtual laboratory, implementing the model in the class and evaluating learning outcomes. **Results:** An innovative learning model equipped with learning resources is available for teaching separation chemistry. The developed model has been convincing effective in facilitating students' active learning and guiding students to complete project assignments. Students are directly involved in implementing their projects contextually, namely separating target analytes, reporting and presenting project products. Thinking skills have been developed, including solution thinking, analytical thinking, evaluation thinking and creating abilities. Students learn thoroughly in achieving chemical separation competencies. The achievement score of thinking skills obtained in the experimental group was higher than that obtained in control class, learning outcomes in the experimental group were higher than the control group. The high normalized gain obtained in the experimental group proves the effectivity of the model in improving learning outcomes. **Conclusion:** The project-based learning model with a virtual laboratory facilitates students' active learning, builds higher-order thinking skills and effectively improves chemistry learning outcomes as a strategy for achieving separation chemistry competence.

Keywords: Higher-Order Thinking Skills, Project-based learning, Virtual Laboratory, Separation Chemistry, StudentsStudents' competence.

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INTRODUCTION

Achieving competency is a very important issue for students when taking courses in higher education, because it relates to their capability to use knowledge and skills for their profession after completing their studies in accordance with the field of science being studied, to be applied in real life.[1] Competency is the main target that must be achieved in learning as required in the Competency Based Education (CBE) or Outcome Based Education (OBE) curriculum, thus learning must be designed to facilitate students to learn optimally to achieve expertise in the field of science being studied.[2] The implementation of the curriculum must be followed by appropriate changes in teaching and learning strategies in accordance with student learning developments, adapting to technological advances, knowledge needs and skills needed to anticipate problems and challenges that will be faced in work. The competencies possessed will be used as a scientific mindset in dealing with challenging situations and solving problems definitely and precisely. This competency is obtained through learning and learning experiences in certain courses and can be obtained through learning that is well planned; implemented and evaluated according to student needs.[3] Attending lectures is a good means of fulfilling skills and knowledge and as a competency needed for work and creativity after completing studies.

Knowledge and analytical skills are competencies that science students need in their work after completing their

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studies. As chemists, pharmacists and other scientists must be competent in analyzing chemical compounds, that is, have the knowledge and skills to know and confirm the presence or existence of the target analytical compound in the sample.[4] The competence on analytical chemistry is used in work related to the qualitative and quantitative determination of chemical compounds. Qualitative determination is needed to ensure the presence of a target compound or analyte in the sample before proceeding to quantitative determination. In quantitative steps, it is often necessary to separate the target analyte to obtain the analyte in its pure state. Separating the target analyte from the mixture requires a purification strategy for a compound so that quantitative determination can take place properly.[5] Thus, knowledge and skills in separating target compounds from their mixtures are crucial in the success of quantitative determinations. In circumstances like this, the analyst must be skilled at using various analytical separation techniques that are appropriate to the target compound to be separated. Separation chemistry competency, namely a combination of knowledge and skills in separating target analytes properly and correctly. Various separation techniques have been used to ensure the presence of target analytes, both classically using simple methods and modernly using instrumentation.[6-8] Separation uses basic chromatography, hereinafter referred to as chromatography, as a simple method for separating target analyte compounds from mixtures. The principles of chromatographic separation as basic knowledge in techniques for separating target compounds must be known to be able to understand modern separation principles. Various chromatographic separation techniques include paper chromatography, Thin Layer Chromatography (TLC), Column Chromatography (CC). In practice, chromatographic separation is generally carried out to screen for the presence of a target compound to optimize the success of separation techniques using Gas Chromatography (GC) or Liquid Chromatography (LC).[9,10]

Separation chemistry is very necessary for students to gain the skills in separation chemistry, to practice separating target compounds from mixtures properly based on the type and characteristics of the sample. The problem faced is the lack of knowledge and skills of students in separating target analytes correctly. Students are also not capable of selecting and determining the appropriate separation method according to the target analyte. Learning that requires students to have knowledge of separation chemistry by memorizing without practicing it makes learning monotonous, boring and meaningless.[11] This is because separation chemistry teaching tends to be dominated by concept improvement and minus practice, resulting in incompetence in separation chemistry. To overcome the problems above, it is necessary to carry out learning innovations to direct students to be directly involved and responsible in their learning. Innovation in learning models through active learning as an alternative for teaching students to achieve competency in separation chemistry. Innovating learning through a project-based learning model will be able to actively involve students in teaching and learning activities. Students must be facilitated with adequate knowledge to be able to carry out their projects well through the provision of innovative learning resources. Learning resources that are complete, systematic and integrated with virtual laboratories are the right choice for teaching students before carrying out a separate project. Through project-based learning with virtual laboratories, students will be facilitated to learn actively, using thinking skills to complete separation chemistry projects.[12]

Thinking skills are life skills for pharmacists and scientists that are needed to solve scientific problems. This skill is related to the ability to use systematic steps and strategies in describing scientific problems and at the same time finding the best way to solve problems.[13] This skill as a cognitive process involves knowledge in collecting, analyzing, processing and concluding information obtained from investigative activities. Various types of thinking skills are used in science such as Critical Thinking Skills (CTS), Higher Order Thinking Skills (HOTS), Complex Thinking Skills (CxT).[14] These thinking components include critical and logical problem solving, reasoned thinking through analysis and evaluation and the ability to be creative in decision making.[15] HOTS involves learning processes such as analyzing, synthesizing, solving problems, controlling information and finding the best way to creative scientific activities.[16] These thinking skills include the ability to analyze, evaluate, set goals, collect and analyze information, process data, estimate, generalize, synthesize and draw decisions critically and systematically. These skills facilitate scientists in understanding scientific problems holistically and using scientific steps systematically including observation, identification, data collection, analysis, interpretation, reflection, evaluation, inference, drawing conclusions and finding the best way to solve problems.[17] The skills mentioned above are built through study and practice as a strategy in achieving the proposed target competence.

Selecting and establishing the right learning model is the key to success in teaching science, including separation chemistry. Implementation of an appropriate learning model will have a direct influence on teaching and learning activities, as a strategy to optimize student learning potential to achieve the competency targets that have been set. Various studies have demonstrated the effectiveness of active learning models in teaching chemistry and pharmacy, including using projects, problem-based, inquiry, case studies and giving assignments which have proven successful in facilitating students to learn optimally to achieve competency targets.[18-20] The active learning model will be effective and successful in facilitating students' learning if it is equipped with the availability of innovative learning resources. The development of science following advances in information technology and digitalization has changed students' daily lives and has immediately influenced their learning patterns. Students tend to forget traditional learning sources such as textbooks and switch to digital learning resources following the culture and daily lives of students. Learning innovations to provide learning resources that are adaptive to students' learning needs need to be carried out with the aim of providing learning facilities that follow daily life and ways of learning, speeding up access to appropriate learning resources and the relevance of learning needs to the challenges being faced and anticipating very rapid changes. Thus, providing innovative digital-based learning resources is very appropriate in facilitating students to learn easily and efficiently, building thinking skills and improving learning outcomes as an implementation of achieving competency. Implementation of a project-based learning model with virtual laboratories is one option that can intervene in students' learning easily, make them strong learners utilizing available resources and as a strategy to achieve separation chemistry competence.[21] The aim of this research is to develop an innovative project-based model with virtual laboratories to build high-level thinking skills, as a strategy for achieving the competency of chemical separation. The focus of the research is to study the effectiveness of the developed learning model in facilitating students' active learning, optimizing learning potential in separation chemistry courses. A Project-Based Learning model with a Virtual Laboratory (PjBL-VL) is used to teach chromatography, which is one of the very important topics as a basic knowledge in Separation Chemistry course.

MATERIALS AND METHODS

Population and Sample

The study was carried out in the even semester of the academic year 2023/2024 at the Department of Chemistry, Faculty of Mathematics and Natural Sciences, involving undergraduate students taking Separation Chemistry courses. The research population and sample are summarized in Table 1. The research sample was selected from 4 parallel classes, made into two intervention groups, namely 3 experimental classes that were given PjBL-VL teaching and 1 control class that was given conventional teaching with practicum. The selected samples were students who had agreed to be samples and had filled out an informed consent form following the research ethics code applicable at the University. The sample of students included in the calculations in this study had almost the same relative level of knowledge, which was sorted from the pretest score.

Research Ethics

The research has been done following the code of ethics for research in the social sciences in the field of education established by the University Ethics Committee. Research repondents were first given a clear explanation of the purpose of the research, the conditions and procedures carried out in carrying out the research and the respondent's participation as a research object, followed by asking for their willingness to fill out an informed consent form as a sign of agreement to be included as a source of research data. Respondents are freely to withdraw from their participation in the research object at any time as they wish if deemed necessary and will not affect the assessment in their study.

Research Procedures

The study was performed in three stages, namely the development and standardization of learning resources, the PjBL-VL implementation stage, the evaluation and follow-up stages, as summarized in Figure 1.

Development and standardization phase of PjBL-VL

A survey of the need for the PjBL-VL model for teaching Separation Chemistry on the subject of Basic Chromatography was distributed to experts, namely lecturers who have experience in teaching Separation Chemistry. Respondents were given a teaching plan for the topic of Chromatography, learning tools and assessment sheets. Respondents were given the freedom to assess the learning model and provide input on the content of the teaching material and teaching scenarios towards achieving teaching objectives, assessing the suitability of the PjBL-VL model to student needs and the potential for achieving separation chemistry competencies. Respondents' opinions are used as a starting point in developing innovative resources that are adapted to the PjBL-VL model.

The development of the PjBL-VL model is carried out through providing learning resources for the subject of Chromatography, enriching teaching materials and providing contextual examples, integrating mini-projects relevant to the sub-subjects, providing virtual laboratories, completing learning support facilities such as project implementation guidelines, templates for project proposals and reports, observation sheets, hyperlinks to relevant articles and websites for further study, HOTS achievement assessment rubrics for project products and practicum reports and evaluation of learning outcomes along with answer keys.

Standardization of the PjBL-VL model is assessed by experts, namely internal and external lecturers. Respondents were given a closed questionnaire accompanied by the PjBL-VL model and learning support devices to be assessed using a Likert scale. Determining the feasibility of the PjBL-VL model is guided by the criteria set by the Indonesian National Education Standards Expert Council (INESEC). Input from respondents was used in revising the PjBL-VL model and fulfilling complete learning facilities.

PjBL-VL implementation stage for teaching chromatography

The PjBL-VL model is implemented in Chromatography teaching, including initial evaluation, learning implementation and final evaluation. The pretest was carried out to see students' mastery of the subject matter as well as homogenize the sample and continued with an explanation of the competency targets to be achieved. The PjBL-VL model was implemented in the experimental class and as a comparison classical teaching with practicum was applied in control class. Short lectures and explanations of the rundown studies were carried out, followed by providing instructions and guidance on the use of e-learning facilities and the university Learning Systems Network (LSN) and their facilities, explanations of subjective assessment rubrics for project products and practicums. The application of the PjBL-VL model in the experimental class is carried out by providing project tasks (project proposals and the reports) to be uploaded into LSN. Guidance by the instructor to improve proposals is carried out according to the speed at which students upload proposals and project implementation and learning activities are carried out after obtaining approval from the instructor. The practicum is carried out in the control class using a guidebook provided by the laboratory and the practicum report is uploaded to LSN. Students in the control class are given teaching on the same topics as in the experimental class, namely through conventional learning followed by giving assignments and carrying out practical activities in groups in the laboratory using the Practical Guide book. Students in control classes are also required to submit practical reports according to the specified time limit. Teaching and learning activities in both treatment groups are presented in Table 2. Students present their findings via zoom before writing a project implementation report. Project proposals, project reports and practicum reports are assessed by instructors using subjective assessment rubrics directly on LSN and can be seen by students. Guidelines for giving grades to learning products, project plans, project reports and practicum reports are given to lecturers. A final evaluation is carried out at the end of study with aimed to measure learning achievement using an objective evaluation of multiple-choice questions covering students' mastery of knowledge in separation chemistry.

Measurement system and evaluation of the PjBL-VL model

Learning achievement is expressed in the form of scores, which are scored from HOTS subjective assessments if students' task and the objective evaluation by using multiple choice tests. HOTS scores are obtained from project assignments (Proposals and Reports) and practicum reports using the HOTS scoring rubric. There are four components of HOTS that are assessed, including problem solving thinking skills (Solution thinking), analytical thinking skills (Analytical thinking), evaluating thinking skills (Evaluative thinking) and creative thinking skills (Create ability), each component on a score scale of 1-100. Scores of learning outcomes are marked from students' ability to answer multiple choice questions correctly and are converted into a score of 1-100. Objective evaluation is carried out for the pretest and posttest, describing the level of student mastery of the chemistry

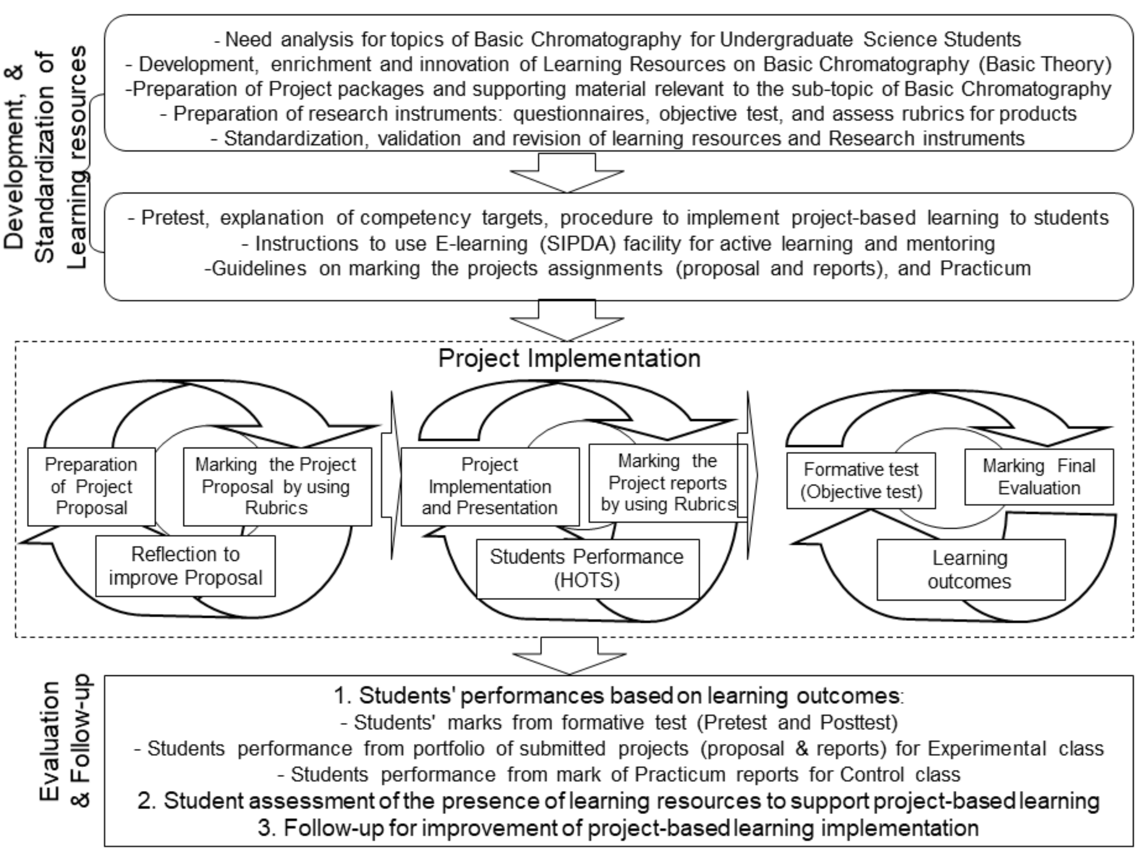

Figure 1: Stages of development, standardization and implementation of the PjBL-VL model for teaching Chromatography.

Table 1: Distribution of population and samples of second year undergraduate students for the implementation of the PjBL-VL model in teaching Chemical Separation.

Sl. No.	Study Program	Population		Sellected Sample	
		Parallel class	Students	Experimental Class*	Control class
1.	Chemistry Education	5	140	2(27)	1(27)
2	Chemistry Education Bilingual	1	14	1(14)	0
3.	Chemistry	2	66	0	0
	Total	7	224	(3)68	1(27)

*Agree to be involved in the study followed by the research ethics given by the university.

Table 2: Teaching and learning activities in the implementation of the PjBL-VL model and Classic-Practicum for teaching Chromatography.

Sl. No.	Teaching and learning activities	Experimental Class		Control Class	
		Activity	Implementation	Activity	Implementation
1	Short lectures, assignments, explaining teaching and learning scenarios, learning objectives and achievement targets.	In the class.	Offline	In the class.	Offline
2	Distribution of learning resources and virtual laboratories, learning instructions, explanations of how to use online learning system facilities and assessment systems.	In the class and via web.	Offline	In the class and via web.	Offline
3	Learning strategies for teaching Chromatography.	Model PjBL-VL.	Offline and Online.	Classic method	Offline and Online.
4	Learning assignments and task.	Mini Projects.	Offline	Practikum	Offline
5	Learning products.	Project reports and presentations.	Offline and Online.	Practical Report	Offline and Online.
6	Learning evaluation techniques and measuring learning motivation.	Pretest, HOTS achievements, Posttest, Questionnaire.	Offline	Pretest, HOTS achievements, Posttest, Questionnaire.	Offline

topics that have been studied before and after the learning implementation. Learning mastery is concluded based on the achievement of HOTS scores and learning outcomes, expressed as achievement of competency targets. Data analysis was seen from the average, difference test (t-test) and correlation (Pearson Correlation) at the significance level (α 0.05). The effectiveness of the PjBL-VL model can be valued from the amount of Normalized Gain (N-G). The assessment of the feasibility of the PjBL-VL model was assessed using a survey package on a Lickert scale with four choices, the criteria for the strongest choice being score (4), decreasing to the weakest choice being score (1). The assessment of learning experiences using the PjBL-VL model was captured using a questionnaire on a Lickert scale with 5 options, sorted from the strongest score (5) to the lowest score option (1). Follow-up actions to improve the implementation of the PjBL-VL model for teaching are carried out based on reflections on student learning achievements in separation chemistry.

RESULTS

PjBL-VL Model and Supporting Facilities for Teaching Chromatography

A project-based learning model that integrates virtual laboratories has been developed for science students, meets the needs for separation analysis skills and knowledge and is in line with student learning developments. The innovative learning model is equipped with learning resources, virtual laboratories and learning support tools for the topic of Chromatography. Teaching materials are prepared to complement basic knowledge about chromatographic separation, which is necessary for students to study advanced chromatography. The topic of chromatography consists of four sub-topics, arranged systematically containing complete teaching materials, virtual laboratory integration and examples of mini projects, which will be used to guide students in active learning and carrying out project assignments. The PjBL-VL model and its supporting equipment have been assessed for their feasibility and suitability of teaching materials based on the proposed competency set in the OBE curriculum. Brief information about innovative resources, descriptions of innovations and responses from the lecturer team regarding the suitability of teaching materials for teaching Chromatography are summarized in Table 3. The PjBL-VL model, learning resources and supporting equipment were declared suitable (M=3.72±0.50) for use in teaching separation chemistry. The content of the teaching materials in each sub-topic and the innovations carried out fulfill the requirements as learning resources to be used in achieving the teaching objectives of separation chemistry.

Standardization of Learning Resources for the PjBL-VL Model

The feasibility of learning resources as part of the PjBL-VL model has been tested by experienced lecturers. The parameters investigated include the appropriateness of the content, completeness of teaching materials, appearance, systematics, design, language and readability, all of which are summarized in Table 4. Conclusions from the validation results of internal lecturers (M=3.58±0.70) and the external lecturers (M=3.65±0.60) states that the developed resiurce meets the learning criteria and is adaptive to the PjBL-VL model.

Implementation of the PjBL-VL Model for Teaching Chromatography

The implementation of the PjBL-VL model has a great influence on teaching and learning activities. The PjBL-VL model facilitates students' active learning in studying separation chemistry. Students actively participate in lectures and complete project assignments, starting from proposing, implementing and writing priject reports. The availability of innovative learning resources in the PjBL-VL model has succeeded in facilitating students to master separation chemistry and project examples have helped students to complete project assignments. Students optimize their learning potential through implementing projects, discussing with instructors and uploading learning products according to

Table 3: Brief description of Chromatography teaching materials that are adaptive to the PjBL-VL Model and suitability of teaching materials to learning objectives based on lecturer assessment.

Sl. No.	Sub Subject	Components of teaching materials in Sub-topics	Brief description of teaching materials, innovation and virtual laboratories	Mini projects and Multimedia	Respondents' opinion*
1	Introduction to Chromatography.	Introduction to Chromatography, chromatographic separation, principles of separation and chromatographic dynamics and basic theory of chromatography.	(1) Introduction to chromatography as an enrichment of knowledge on separation using basic chromatography, as a basis for separation in modern chromatography. (2) Virtual laboratory to illustrate the principles of chromatographic separation to separate analytes from mixtures to produce pure compounds which are influenced by stationary phase, mobile phase and chromatographic dynamics. (3) Basic concepts of chromatographic analysis and chromatographic classification schemes.	Project 1: Schematic for chromatography classification according to the packing of the stationary phase.	3.78±0.44
2	Types of Chromatography based on the method of separation (force of separation).	The principles of chromatographic separation include: (1) Adsorption chromatography, (2) Partition chromatography, (3) Ion exchange chromatography, (4) Size Exclusion chromatography, (5) Ligand exchange chromatography, (6) Pair ion chromatography and (7) Affinity chromatography.	(1) Type of chromatography based on the method of separating the target analyte from the mixture by the influence of the interaction between the target analyte and the stationary phase (using various types of stationary phase) including adsorption, partition, ion pairs, ion exchange or ligand exchange, size exclusion and affinity. (2) Virtual laboratory to explain separation techniques and procedures based on force of separation illustrate the different methods of separation based on force of separation and describe the movement of analytes in the stationary phase.	Project 2: Design and manufacture a chromatography column using various types of stationary phase (selection of a variety of materials to be used as stationary phase and mobile phase).	3.56±0.73

Sl. No.	Sub Subject	Components of teaching materials in Sub-topics	Brief description of teaching materials, innovation and virtual laboratories	Mini projects and Multimedia	Respondents' opinion*
3	Types of Chromatography based on packing of the stationary phase.	The basic principles of separation use various types of packing of the stationary phase, including: (1) Thin Layer Chromatography (TLC): the stationary phase is a thin layer supported on glass, plastic or aluminum plates, (2) Paper Chromatography (PC): the stationary phase is a thin film of liquid supported on an inert support and (3) Column Chromatography (CC): stationary phase is packed in a glass column. Applications and examples of separating target analytes using: (1) Thin Layer Chromatography (TLC), (2) Paper Chromatography (PC) and (3) Column Chromatography (CC).	(1) Chromatography design based on variations in packing of the stationary phase to separate analytes from mixtures using various types of materials as stationary phases according to the target analyte. (2) Virtual laboratory integration to explain separation techniques and procedures using paper chromatography, thin layer chromatography and column chromatography. Illustration of the speed and selectivity of separating target analytes from mixtures through the use of various types of materials as stationary phases, using various types of mobile phases, variations in mobile phase concentrations, strategies for identifying and confirming target analytes and how to collect them for the next analysis process.	Project 3: Separation using Thin layer chromatography to separate organic compounds 4. Project 4: Separation using Column chromatography for the separation of organic compounds (Bioactive compounds).	3.67±0.50
4	Application of Chromatography for Separation of Target Analytes in Real Samples.	Application of chromatography for the separation of inorganic compounds and organic compounds. Examples of target analyte separation using: (1) Thin Layer Chromatography (TLC), (2) Paper Chromatography (PC) and (3) Column Chromatography (CC).	(1) Demonstration of the separation of target analytes from real samples by chromatography using various techniques including: Thin layer chromatography, Paper chromatography and Column chromatography. (2) Virtual laboratory to make it easier for students to understand chromatographic separation, including preparation, equipment design, experimental procedures, sample treatment and calculation and reporting techniques for the separation of various types of target analytes such as food colorings and inorganic compounds using paper chromatography, separation of organic compounds using TLC and CC and water demineralization process using ion exchange.	5. Project 5: separating and identifying food coloring substances by chromatography (PC and CC) 6. Project 6: separating and identifying Alkaloids, Flavonoids, from Terpenoids from various types of medicinal plant materials by chromatography (TLC and CC).	3.89±0.33
	Average				3.72±0.50

the set deadline. Students in the experimental class have used thinking skills in planning their projects, seriously discussing contextual project task options, completing projects through data collection, reporting results and uploading project reports. The project's chosen topics were varied and contextual and included chromatographic separation (Table 5). At the same time, students in the control class also did practicums and uploaded practicum reports.

Achieving competency is the main target in implementing the PjBL-VL model in teaching separation chemistry. Teaching and learning activities are dominated by students, who have utilized learning resources as the main source of knowledge in understanding the principles of chromatographic separation in their project assignments. Success in project planning will speed up the completion of separation projects using paper, thin layer and column chromatography. Students understand the role of various types of eluants in separating target analytes in the stationary phase using cellulose or silica. Students have also been able to identify compounds that are separated qualitatively and quantitatively. Students successfully choose a basic chromatography method that suits the target analyte contained in the raw material (sample). Students have reported learning products in the form of project reports. Success in separating and identifying target analyte compounds from raw materials (samples) proves students' mastery of chromatographic separation techniques. They are skilled in designing chromatography techniques according to the characteristics of the target analyte, have chosen the right stationary phase and eluent composition and carried out calculations correctly. The HOTS score based on the assessment of learning products is summarized in Table 6. Students in the experimental group obtained the HOTS achievement for the project plan (M=77.17±5.31) which was classified as good and for the project report (M=88.12±4.58) which was categorized as very good. The HOTS scores on the solution thinking, analytical thinking, evaluation thinking and creative ability components in the experimental class are all classified as very good. These HOTS score achievements in experimental treatments were higher than the score of the practicum report of the control group (M=73.09±3.18), namely in the good category.

Student involvement in projects is proven to build students' higher order thinking skills (Table 6). Students have used their thinking skills to complete their project assignments and this has influenced their knowledge of separation chemistry. The PjBL-VL model has guided students to learn optimally and HOTS has become an intermediate strategy in achieving separation chemistry competency. Student learning outcomes based on learning evaluations are summarized in Table 7. Before teaching, students in the two treatment groups had relatively similar mastery of chromatography, namely the experimental group (M=24.64±4.06) and the control group (M=24.67±3.68) and both groups' treatments were not significantly different (t-stat -0.109<t-crit 2.055, α 0.05). The results revealed that student learning outcomes increased significantly, the average score obtained by students in experimental group

Table 4: Results of internal and external lecturers' assessments of the suitability of learning resources to support the PjBL-VL model.

Sl. No.	Criteria and brief description of learning resource assessment components	Respondents' opinion (*M*±*Sdv*)	
		Internal (*n*=5)	External (n=4)
1	**Content Feasibility:** describes the completeness and depth of the content of Chromatography teaching material for undergraduate students.	3.60±0.70	3.88±0.35
2	**Completeness of learning resources:** Includes the availability of learning resource packages and supporting facilities such as mini projects, virtual laboratories, project implementation guides, student worksheets, templates (project proposals and reports), appropriate sample questions, practice questions and answer keys, hyperlinks on the site website, learning evaluation and HOTS assessment rubric.	3.60±0.70	3.50±0.93
3	**Systematics and Display:** Describes the systematics of learning resources and virtual laboratory displays, the suitability of the mini project package with learning objectives and the relevance of the project to the application of separation chemistry in everyday life.	3.70±0.67	3.63±0.52
4	**Design and accuracy:** Describing the attractive design of learning resources and virtual laboratories including typesetting, layout of teaching materials, color selection, layout of pictures, tables, schemes and illustrations, accuracy of writing formulas and chemical reaction equations.	3.47±0.71	3.42±0.74
5	**Language and readability:** Describes the simplicity and readability of the content of teaching materials, including the use of language and grammar according to the student's maturity level, the accuracy of using terminology, the clarity of virtual laboratory messages and the placement of interactive learning facilities.	3.53±0.70	3.83±0.46
	Average	3.58±0.70	3.65±0.60

*Likert scale: (4) Very Appropriate; (3) Appropriate; (2) Not Appropriate; and (1) Very Inappropriate.

Table 5: Themes and topics of chromatography separation projects selected and completed by students in groups (*n*=68).

Sl. No.	Selected project assignment topics	Project product upload	
		Proposals	Reports
1	Paper chromatography for the separation and identification of food coloring compounds uses various types of solvents.	2	2
2	Thin layer chromatography for the separation and identification of bioactive compounds from medicinal plants uses various types of solvents.	5	5
3	Column chromatography for the separation and identification of bioactive compounds from medicinal plants uses various types of solvents.	10	10
4	Ion exchange chromatography uses activated zeolite as the stationary phase.	1	1
	Total	18	18

(M=86.88±4.97) was found higher than the average marks of control class (M=77.15±3.54) and the two groups were assigned to be significantly different (t-stat 8.071>t-crit 2.055, α 0.05). The N-Gain value in experimental group (N-G=0.83) was greater than value of the control group (N-G=0.70), confirming the effectiveness of the PjBL-VL model in improving learning outcomes. Students who studied using the PjBL-VL model were very competent, while the control group students were classified as competent. Pearson correlation analysis has been carried out to see the contribution of HOTS achievements to learning outcomes in the application of the PjBL-VL model, namely that a positive correlation was obtained between HOTS and students learning outcomes (r=0.90-0.94). This perfect correlation confirms that HOTS contribute to improving learning outcomes. The PjBL-VL model facilitates active learning for students, can be relied on to teach students to master separation chemistry holistically and achieve separation chemistry competency.

The Influence of the PjBL-VL Model on Learning Motivation

The implementation of the PjBL-VL model is aimed at intervening in student learning activities and its influence in motivating learning has been investigated as presented in Table 8. Positive responses (M=4.42±0.60) were given by students for the contribution of the PjBL-VL model to teaching and learning activities. The developed learning model is successful in focusing students to actively learn to study Chromatography. The PjBL-VL model is successful in optimizing student learning potential, guiding them in planning, implementing and reporting their projects correctly. Various aspects of motivation such as confidence, engagement, challenge, curiosity, relevance and satisfaction are valued very good. Teaching and learning activities succeeded in building HOTS and increasing students' knowledge as a strategy in achieving separation analytical chemistry competence. It was concluded that the PjBL-VL model is efective to motivate students to do active learning to achieve separation chemistry competency.

DISCUSSION

Implementation of the PjBL-VL model is keys in optimizing student learning potential in studying separation chemistry. This learning model has proven to be effective in facilitating students' active learning by utilizing study resources and virtual laboratories in understanding the principles of separating target analytes using chromatography.[22] The standard resource package has been adapted to the characteristics and development of student learning, acting as a single resource for students undertaking separation projects. Innovative learning resources contain knowledge concepts of chromatographic separation, examples of separation projects and virtual laboratories for visualization of separation processes.[23] This learning model provides adequate knowledge of separation and inspires students to get ideas about chromatographic separation contextually. Various basic chromatography techniques have been provided to assist students in selecting the appropriate technique for separating target analytes, assembling equipment, selecting the stationary phase, determining the type and composition of the eluent, identifying and confirming the separated compounds. Innovative learning facilities are effective in teaching students to practice through separation projects. The developed learning model empowers students to study optimally in mastering the concept of chromatographic separation and applying it in practice to separate target analytes correctly.[24]

This study shows that students have successfully chosen the type of chromatography method, have planned a separation project and demonstrated success in carrying out separations using various types of chromatography according to the target analyte. Through projects, students are facilitated to be directly involved in active learning, building HOTS as a steps in inmproving students knowledge for achieving the proposed target competency of separation chemistry.[25,26] The application of the PjBL-VL model guides students to use their thinking skills as scientific steps in completing separation projects and as a key to success in mastering the students with predetermined competency targets.[27,28] Various separation projects have been designed and

Table 6: HOTS scores from the assessment of learning products from chromatographic separation: project proposals and reports and practicum reports.

Sl. No.	Aspect of HOTS	Description of thinking skills	Students' achievement ($M \pm Sdv$)		
			Experimental class (n=68)		Control class (n=30)
			Project proposals	Project reports	Practicum reports
1	Problem Solving (Solution thinking).	Skills in solving separation problems through selecting chromatographic methods, designing projects to separate target analytes based on the characteristics of the target compound, selecting the type of chromatography based on the packing of the stationary phase and understanding chromatographic separation techniques contextually.	71.62±5.52	86.28±4.90	71.88±4.55
2	Analytical thinking	Have the skills to analyze chromatographic separation steps according to the target analyte, including: identification of target compounds, selection of basic chromatography types, selecting stationary and mobile phase, reagent preparation, preparing equipment, sample treatment, separation strategy, identifying target analytes, recording results, processing data and conclude the correctness of the target analyte resulting from the separation.	76.39±5.26	88.47±4.90	71.64±6.85
3	Evaluation thinking	Have the ability to evaluate the results of separation analysis of target analytes based on the type of chromatography, distinguish chromatography efficiency in the ability to separate target compounds using variations in mobile phase concentration, express scientific views on findings based on project data and assess the quality of data scientifically.	77.75±5.35	88.59±4.35	75.28±5.37
4	Creative thinking	Ability to creatively generate new ideas for chromatographic separation of target analytes, innovate and modify existing chromatographic techniques to be applied in own projects, establish chromatographic techniques for separation of target analytes correctly, quickly and efficiently and scientific arguments to convince the originality of chromatographic techniques which has been selected in separating target analytes contextually.	76.66±5.40	87.31±4.48	74.08±4.92
Average			76.93±5.31	88.12±4.58	73.67±5.07

*Obtained from a subjective assessment of the proposal and project report and practicum reports by using HOTS rubrics.

implemented contextually and the separation principles applied generally follow procedures such as the separation examples provided in the learning resources with modifications.

This study demonstrated that the implementation of the PjBL-VL model was successful in empowering students in selecting and defining chromatographic separation topics contextually and successfully separating bioactive compounds from various types of medicinal plant samples. Students have reported the findings of separation projects and increased their knowledge of the potential of ethnic plants as sources of bioactive compounds for medicinal raw materials.[29-31] HOTS's achievements from the project product assessment are classified as very good, including solution thinking, analytical thinking, evaluation thinking and create ability. Solution thinking relates to choosing the right and effective type of chromatography to separate the target analyte. Analytical thinking skills are related to determining the eluent concentration by using a suitable stationary phase in the chromatographic method to separate the target analyte compound. Evaluation thinking is related to the search for optimum conditions for an effective and efficient experiment in chromatographic separation based on the use of variations in the type and concentration of eluent. Meanwhile, creating ability is demonstrated by students' success in modifying chromatography techniques for better analytical separation and they will even find new techniques to separate target analytes easily, selectively, quickly and are safe for the user. The implementation of the project has provided a bridge for students to use thinking skills to learn optimally in achieving the separation analytical chemistry competency target. A high HOTS score obtained in the experimental group becomes the evidence for the PjBL-VL model ti be appropriate in facilitating separation chemistry teaching and resulted in increased student mastery of the subject being studied. This study also demonstrates a positive relationship between HOTS achievement and improved learning outcomes. The high normalization of gain in the experimental group proves the effectiveness of the PjBL-VL model to increase learning outcomes to achieve the competence of chemical separation.

In this study, several possible potential bias factors that could influence learning outcomes have been anticipated, such as the selection of sample groups for treatment, attention and response to the needs of students' difficulties and giving HOTS marks to student project and practicum report products. These

Table 7: Student learning completion based on learning outcomes in implementing the PjBL-VL model for teaching Chromatography.

Sl. No.	Intervention Class	Students (*n*)	Learning outcome (*M±Sdv*)			N-Gain	Achievement of Competency Targets
			Project report or Practicum report *	Pretest*	Postest*		
1	Chemistry Education A	27	88.73±4.38	24.64±3.97	86.88±4.97	0,83	Very competent
2	Chemistry Education D	27	86.76±4.50	24.32±4.23	86.71±4.97	0,82	Very competent
3	Chemistry Bilingual	14	88.88±4.85	24.43±3.98	89.11±2.42	0,86	Very competent
4	Chemistry Education B (Control)	27	73.67±5.07	24.67±3.68	77.15±3.54	0,70	Competent

* Obtained from portfolio of submitted projects or practicum.** Obtained from the avarage of objective test.

Table 8: Student assessment of the contribution of the PjBL-VL model in motivating students to optimize their learning potential in teaching Chromatography.

Sl. No.	Aspect of motivation	Item Question	Assessment indicators and description	Respondents' opinions (*n*=34)
1	Confidence	2	The PjBL-VL model with innovative learning resources facilitates students' active learning.	4.44±0.66
2	Challenge	2	The facilities available in the PjBL-VL model help students in selecting and setting separation projects contextually and are challenged to find the best conditions through variations in type and concentration of eluent to separate the target analyte from the mixture.	4.38±0.55
3	Engagement	2	Students are directly involved in using learning resources and implementing knowledge in completing chromatographic separation projects.	4.56±0.50
4	Curiosity	2	Students are determined to prove the success of the chromatography separation project to produce pure target analytes quickly and efficiently.	4.35±0.60
5	Relevance	2	Implementation of the PjBL-VL model is very relevant for optimizing learning potential and is a good strategy for achieving separation chemistry competency.	4.44±0.70
6	Satisfication	2	Students are very satisfied with the implementation of the PjBL-VL model, leading to successful chromatography project assignments and providing a long-lasting learning impression.	4.32±0.59
Sum/Average		12		4.42±0.60

*Likert scale: (5) Strongly Agree; (4) Agree; (3) Neutral; (2) Disagree; and (1) Strongly Disagree.

factors have been minimized through sample homogenization based on pretest scores, namely removing sample outliers in data processing, as a guarantee that students' initial knowledge before learning is the same in the experimental group and in the control group. Services for student difficulties have been provided optimally online and offline. Subjective factors originating from the HOTS assessment to assess student assignment products are minimized through assessment instruments using the HOTS rubrics which are carried out by the same lecturer or instructor for both treatment groups. Another factor that is difficult to control is the interaction between students in two different groups who may have used learning resources provided for the experimental group but were also used by students in the control group Implementation of PjBL-VL model greatly influences teaching and learning activities and student learning motivation.[32] They have utilized learning resources optimally for learning and carrying out project assignments, changing teaching and learning activities to be student-centered, improving learning outcomes and ultimately influencing competency achievement. Through the implementation of the project, aspects of motivation such as students' confidence, learning challenge, study engagement, scientific curiosity, project relevance and study satisfaction are allassigned to be in the very good category. This study proves that students in the experimental group were directly involved in applying the knowledge learned into practice through projects, succeeded in finding target analyte compounds contextually and the impression of learning was long remembered.[33] The PjBL-VL model is very appropriate to implement for achieving separation chemistry competencies and will be relevant to be applied in other courses to promote thinking skills as a good way to improve learning outcomes and competency achievement.

CONCLUSION

Selection and implementation of a learning model that is appropriate to the characteristics of the course is the key to creating optimal learning activities and influences the success of achieving competition targets. This study has developed a project-based learning model with a virtual laboratory equipped with innovative learning resources for teaching separation chemistry. This PjBL-VL model has been implemented in teaching chromatography to undergraduate students. The research results demonstrate that this innovative learning model is effective in facilitating students' active learning, promote higher-order thinking skills and improving chemistry knowledge and is a good strategy in achieving competency in the field of separation chemistry. An innovative learning resources becomes the key role to implementing active learning to achieve the set competency targets. The integration of virtual laboratories in learning resources makes it easier for students to understand the principles of chromatographic separation and then implement them through contextual chromatographic separation projects. Through the separation project, students' learning potential is optimized and holistic learning is created, students are enthusiastic and challenged to separate various target analytes of bioactive compounds from medicinal plants samples by chromatographic method. The developed HOTS componen including the components of solution thinking, analytical thinking, evaluation thinking and create ability that are scored in the experimental group (M=88.12±4.58) was found higher than that oobtained inthe control class (M=73.67±5.07). Student learning outcomes acheved by the experimental group (M=87.57±4.12) were also found higher than those for control group (M=76.97±3.60) and the two treatment groups were proven to be significantly different (t-stat 8.071>t-crit 2.055, α 0.05). The normalized gain in the experimental group (N-G=0.83) was greater than the control group (N-G=0.70), confirming the high effectiveness of the PjBL-VL model in facilitating stuents to have high learning outcomes and as evidence of the achievement of separation chemistry competency. Students learn optimally, teaching and learning activities are student-centered and project activities provide a learning impression that is long remembered. The learning model developed in this study is very appropriate to facilitate students to proceed active learning, promote higher-order thinking skills and at the same time improve learning outcomes as a strategy to achieve chemical separation competence. The PjBL-VL model is very relevant to be adopted in other courses that need to master the knowledge and skills through learning.

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ABBREVIATIONS

CBE: Competency based education; **OBE:** Outcome based education; **PjBL:** Project-based learning, **VL:** Virtual laboratory; **PjBL-VL:** Project-based learning *v*irtual laboratory; **PC:** Paper chromatography; **TLC:** Thin layer chromatography; **CC:** Column chromatography; **GC:** Gas chromatography; **LC:** Liquid chromatography; **CTS:** Critical thinking skills; **HOTS:** Higher order thinking skills; **CxT:** Complex thinking skills; **INESEC:** Indonesian National Education Standards Expert Council; **N-g:** Normalized Gain; **LSN:** learning systems network.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

SUMMARY

A project-based learning model with virtual laboratories has been developed for teaching separation chemistry. The PjBL-VL model is used to facilitate students' active learning through contextual project work. The developed higher-order thinking skills are used

in completing chromatographic separation projects contextually. The PjBL-VL model has proven effective in facilitating students in completing project assignments to separate bioactive compounds from various types of medicinal plants. Students are directly involved in planning and implementing their projects and report project products well. HOTS's thinking skills have developed, including solution thinking, analytical thinking, evaluation thinking and the ability to create. The HOTS scores and learning outcomes in the experimental group were higher than those in the control class. The high normalized gain obtained in the experimental group confirms the high effectiveness of the PjBL-VL model in improving student learning outcomes and is proof of achieving separation chemistry competency. The PjBL-VL model is relevant to be applied to other courses that require increased knowledge and skills.

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