# The Development of Guided Inquiry-Based Learning Resources as a Strategy to Achieve Student Competence in Analytical Chemistry

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**Abstract.** This study aims to develop and implement an innovative guided inquiry-based learning resource as a strategy for achieving student competence in the teaching of Analytical Chemistry. The research was conducted during the Covid 19 pandemic, involving 30 undergraduate students. Research stages include the development of innovative learning resources with guided inquiry to facilitate students to conduct investigations, include asking, researching, reporting investigation result, and share finding information to hone students higher-order thinking skills (HOTS). A standard inquiry-based learning resource package has been compiled for teaching Cation analysis for undergraduate students. Learning resources and supporting facilities are effective in facilitating students to learn actively in planning and carrying out inquiry assignments and presenting their findings. Thinking skills in the HOTS category have been developed for three aspects, namely the skills to analyze, evaluate, and create for analytical chemistry activities, all of which are classified as very good (M=85.07±1.70). The availability of guided inquiry-based learning resources has succeeded in teaching students to master Cation Analysis, as indicated by the achievement of learning outcomes (M=83.16±4.82) which are classified as good. Guided inquiry-based learning is very appropriate to be used for active learning as a strategy for achieving competence in the field of analytical chemistry

**Keywords:** Guided inquiry; Learning resource; HOTS, Thinking skills; Active learning

## 1 Introduction

The application of innovative learning is a good strategy in achieving student competencies, including competencies in analytical chemistry [1]. Analytical Chemistry is a compulsory subject for undergraduate science students to equip analytical competencies, including separation, identification, and determination. Competence in the field of analytical chemistry combines knowledge with skills in the field of analysis to be implemented for contextual determination of target analytes [2]. Thus, efforts must be made to make the teaching and

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learning process run well by adjusting class conditions to optimize student learning potential to achieve competency targets. Various strategies can be carried out such as implementing teaching and learning strategies, selecting appropriate learning models and methods, and innovating learning [3],[4],[5].

The problem faced is that it is difficult to facilitate active learning for students in achieving Analytical Chemistry competence because they have to combine knowledge and skills. The global situation experienced in the last two years due to the Covid-19 pandemic, namely social restrictions occurred to cut off the transmission of the corona virus, including restrictions on face-to-face learning [6]. Teaching tends to be done online and restricting student access to study in the laboratory makes it difficult to achieve analytical competence. To overcome this problem, a technique is needed to facilitate students to learn independently as a supporter of limited learning in the laboratory following the health protocol set by the university. One strategy that is of concern is the application of guided inquiry to guide students in active learning to conduct investigations [7,8]. Inquiry-based learning requires stages such as asking questions, conducting research, reporting the results of investigations, and sharing information on findings to hone students' thinking skills [9]. This learning model trains students to learn systematically to build their thinking skills, including higher order thinking skills (HOTS) [10]. Learning activities start from identifying problems, carrying out investigations and reporting research results as findings in overcoming problems. Guided inquiry can be integrated with multimedia to make learning interesting, theory and practice are studied in an integrated manner, resulting in the impression of learning being remembered for longer by students [11,12].

The provision of guided inquiry-based innovative learning resources is an option in the teaching of analytical chemistry, as a strategy to optimize the learning potential of students studying Analytical Chemistry. The application of guided inquiry is believed to be a strategy in facilitating active learning in normal and abnormal situations caused by the Covid-19 pandemic. This study aims to develop and implement an innovative guided inquiry-based learning resource to facilitate active learning for students as a strategy for achieving competence in the field of Analytical Chemistry. Innovative learning resources are needed to stimulate critical and analytical thinking, as well as guide students to study systematically to find answers to problems faced in the field of Analytical Chemistry.

## 2 Methods

The research method consisted of population and sample, research procedures, and evaluation of learning outcomes following the research procedures described previously with modifications [13,14].

**Population and Sample**

This research was conducted during the Covid-19 pandemic in the even semester of the 2021/2022 academic year. The research population is students of the Department of Chemistry Education, Faculty of Mathematics and Natural Sciences (FMIPA), Medan State University, involving 30 undergraduate students. This research has complied with the code of ethics for social research in the field of education set by the University. The explanation of the participation of students as samples in the conduct of the research has been explained, they are informed that they will be the source of research data, and students are given the freedom at any time to withdraw from their participation in the study if necessary without affecting their academic assessment

**Reseach Procedure**

The implementation of the research was carried out through the stages of needs analysis of analytical chemistry learning resources, designing and developing innovative learning resources based on guided inquiry and equipped with supporting devices, and implementing learning resources for teaching Cation Analysis to build thinking skills. The preparation of a guided inquiry-based innovative learning resource package for the subject of Cation Analysis was carried out based on a competency-based curriculum. Learning resources contain complete teaching materials, examples of guided inquiry packages, multimedia integration examples of guided inquiry implementation, observation templates and investigative reports and are packaged in digital format. Standardization was carried out using experts, and continued with revisions and refinements of learning resources.

The implementation of learning resources is carried out as a support for online lectures via zoom. The teaching of Cation Analysis is carried out through the initial evaluation stage (pretest) followed by online learning using the University's e-learning facility, the University Learning Portal System (SIPDA), followed by the assignment of inquiry, and evaluation (subjective and objective). Pretest was conducted to see the students' initial ability on the subject of Cation Analysis. Explanations in using SIPDA were given to students in downloading learning resources, uploading inquiry assignments, discussing with instructors online, and seeing the achievement of scores at each stage of the inquiry task implementation. Learning resources are uploaded to SIPDA. Inquiry assignments were carried out through the stages of investigations including: (1) asking questions, (2) conducting research, (3) reporting the results of the investigation, and (4) sharing information on findings. Inquiry proposal assignments uploaded by students were checked by the instructor, and continued with the implementation of inquiry activities after obtaining the instructor's approval. The inquiry is carried out in the laboratory for a certain period of time to comply with the health protocol regulations set by the university, and the output of the inquiry activity is uploaded by students to get an assessment. At the end of the lecture, a final evaluation (post-test) is carried out using multiple-choice objective tests.

**Evaluation of Learning Outcomes**

Achievement of competence is measured based on student scores in inquiry assignments and final evaluations. The score for the inquiry task product (Proposal and Report) was obtained based on the assessment of thinking skills in the HOTS category for analyzing skills, evaluating skills, and creating new findings, using an assessment rubric on a scale of 0-100. Learning outcomes are obtained based on mastery of knowledge based on the final evaluation using multiple choice objective tests, and the score is converted to a value of 0-100. The Lickert scale was used to assess the opinion of the respondents through a questionnaire. Standardization of learning resources is carried out using a questionnaire with 4 choices, with the assessment criteria from the strongest (4) Very Appropriate to the lowest (1) Very Disagree. Learning motivation was captured using a questionnaire with 5 answer choices, ranked from (5) Strongly Agree to the lowest (1) Strongly Disagree.

# 3 Results

## Innovative Learning Resources With Guided Inquiry

Inquiry-based innovative learning resources for the subject of Cation Analysis have been arranged relevant to the sub-topic, equipped with an inquiry implementation guide as summarized in Table 1. The teaching materials consist of the sub-subject of Cation Analysis, examples of inquiry and multimedia guided inquiry implementation, problems and tasks of inquiry , observation sheets, report templates, presentation templates, and assessment rubrics are all packaged into digital learning resources using flipbooks. Teaching materials are arranged systematically and attractively which are linked by trusted web hyperlinks.

**Table 1.** Description of inquiry-based learning resources for teaching Cation analysis

| No | Sub-topics* | Description and innovation of guided inquiry-based learning resources | Inquiry instructions and tasks |
|---|---|---|---|
| 1 | Introduction to Cation Analysis | The teaching materials explain the basic theory of cation analysis, analytical steps for grouping cations into cation groups based on their reactions, and the use of selective precipitating reagents. The innovation is equipped with an inquiry procedure for cation grouping analysis, animation of the implementation of cation grouping inquiry flowcharts, and web hyperlinks for cation analysis. | An example of an inquiry assignment is to make a flowchart of cation grouping based on similarity in nature through the addition of selective precipitants into cation groups. |
| 2 | Cation Grouping and Separation of Single Cation | The teaching material contains strategies for grouping cations based on their solubility, and separating one group into a single cation using selective reagents. The material is equipped with an inquiry procedure to group cations into cation groups and then separate them into single cations. There is a video of the implementation of the inquiry separating a cation group into a single cation using selective reagents, and a hyperlink analysis of the separation of one cation group into single cations. | An example of an inquiry assignment, with the title: Grouping cations into one cation group using selective reagents, and separating them into single cations |
| 3 | Identification and confirmation reactions to cations | Teaching materials consist of identification of the presence of cations, and confirmation of cations using special reagents. The material is equipped with a strategy inquiry procedure to identify single cations, and the use of special reagents to confirm the presence of cations. There is a video showing the implementation of the inquiry as a strategy to identify and confirm the presence of single cations using selective chemical reagents, and equipped with hyperlinks for cation identification analysis. | Examples of inquiry assignments, with the title: (1) Identification and confirmation of the presence of single cations resulting from separation, (2) Separation, identification, and confirmation reactions of cations contained in mineral samples, (3) Separation, identification, and cation confirmation reactions contained in cosmetic samples. |

*Complete materials of Cation Analysis are available in the References [16]

### Standardization of Learning Resources With Guided Inquiry

The feasibility of inquiry-based innovative learning resources for teaching Cation Analysis has been assessed by experts, namely Analytical Chemistry lecturers who have experience teaching Analytical Chemistry for at least three consecutive years. The assessment is carried out based on the suitability of the teaching materials and the completeness of learning resources with the competency targets set in the competency-based curriculum for undergraduate students. The results of the respondents' assessments are summarized in Table 2.

**Table 2.** Results of standardization of guided inquiry-based learning resource packages and their supporting facilities for teaching Cation analysis

| No | Types and criteria of guided inquiry-based learning resources | Respondents opinion* ($M$±$Sdv$) ($n$=2) |
|---|---|---|
| 1 | **Content:** The suitability of Cation Analysis teaching materials, examples of inquiry, multimedia and supporting facilities with the target curriculum based on Analytical Chemistry competence. | 3.54±0.04 |
| 2 | **Extension:** Availability of inquiry assignments, inquiry implementation guidelines, templates for proposals, inquiry reports and presentations, media integration, assessment rubrics, and hyperlinks to learn Cation Analysis. | 3.55±0.46 |
| 3 | **Accuracy:** Systematics and accuracy of writing, accuracy of examples for contextual applications of Cation Analysis, and accuracy of writing symbols, terms and chemical formulas. | 3.61±0.48 |
| 4 | **Design:** Design, layout of images, tables and illustrations, typesetting, and color selection on learning resources, multimedia and learning resource support devices. | 3.66±0.44 |
| 5 | **Language:** Appropriateness of language use, grammar, terminology, legibility, simplicity of content in learning resources, and relevance to students' thinking levels. | 3.56±0.49 |
| | **Average** | 3.58±0.45 |

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

### Implementation of Innovative Learning Resources With Guided Inquiry

The implementation of inquiry-based innovative learning resources is carried out in one class due to the limited use of laboratory resources during the Covid-19 pandemic. Blended teaching is applied, teaching online using a zoom meeting and continuing with the implementation of inquiry tasks in the laboratory. Other activities such as discussions, presentations and questions and answers using SIPDA. The inquiry-based learning model greatly influences the achievement of student competencies. Students have been facilitated to learn independently to increase their knowledge, find the right answers in solving cation analysis problems, make plans and carry out inquiry tasks, report findings and present the results of investigations. Learning achievement is obtained based on subjective assessment of thinking skills and the results of objective assessment.

### Inquiry Learning and Higher Order Thinking Skills

Students successfully attend lectures and have completed inquiry assignments (proposals and reports) which are uploaded to SIPDA on time. The results of the subjective assessment of the proposal and inquiry report for the three aspects of thinking skills are summarized in Table 3. Student achievement from the inquiry report was very good, on average (M=85.07±1.70). Sequentially scores for analytical skills (M=84.33±2.45), evaluation skills (M=85.17±2.67), and creativity skills (M=85.70±1.74) were all in the very good category.

**Table 3.** Subjective assessment of higher order thinking skills based on product proposals and inquiry reports

| No. | HOTS Components | Description of thinking skills | Learning achievement score for inquiry tasks (*M*±*Sdv*) (*n*=30) | |
|---|---|---|---|---|
| | | | Proposal | Reports |
| 1. | Analize | The ability to think analytically in solving problems using qualitative analysis, including: type of sample, sample treatment, determining precipitating compounds to separate cations, determining specific reagents to be able to discriminate, identify, and confirm the presence of the target analyte. | 79.83±3.34 | 84.33±2.45 |
| 2. | Evaluate | The ability to think systematically in evaluating an inquiry task to determine cations qualitatively, starting from identifying the target analyte contained in the sample using a theoretical approach, considering several alternative precipitating compounds that are selective to precipitate and separate the target analyte, and decide on the most appropriate strategy in identifying and confirming the target analyte compound in the sample. | 81.53±4.96 | 85.17±2.67 |
| 3. | Create | Ability to determine the best method for cation analysis, skills in modifying new analytical procedures to get better, faster and accurate findings in qualitative determination of cations. | 80.17±4.63 | 85.70±1.74 |
| | | Average | 80.51±4.32 | 85.07±1.70 |

*Obtained from a subjective assessment using the criteria in the assessment rubric of the guided inquiry

### The Effect of Inquiry-Based Learning on Learning Outcomes

The main objective of developing innovative guided inquiry-based learning resources is to facilitate active learning for students to achieve their competencies, which is indicated by increasing knowledge and skills in analytical chemistry needed for life skills afterward.

Student learning outcomes from the implementation of innovative learning resources are summarized in Table 4. There was an increase in learning outcomes as indicated by the average achievement of learning outcomes at the end of learning (M=83.16±4.82) compared to before learning (M=47±9.61). Mastery of students in Cation Analysis is classified as very good.

**Table 4.** Student learning outcomes based on pretest and posttest on teaching of Cation Analysis

| No | Learning evaluation | Learning achievement score (*n*=30) |
|---|---|---|
| 1 | Pretest | 47±9.61 |
| 2 | Posttest | 83.16±4.82 |
| Difference between posttest and pretest | | 36.16 |

### Guided Inquiry Based Learning Resources and Student Learning Motivation

The success of students in achieving curriculum competency targets is largely determined by the students, because studying in higher education is dominated by motivation in utilizing available learning resources. The effect of the availability of inquiry-based innovative learning resources in facilitating students' active learning has been captured as summarized in Table 5. The learning components that influence students' learning such as confidence, challenge, engagement, curiosity, relevance, and satisfication are all in the very good category (M=4.34 ±0.83). This result is the effect of the application of inquiry-based learning that motivates students to learn actively independently. The inquiry-based learning resource package motivates students to optimize their learning in analytical chemistry, and is proven by the achievement of competence in the field of analytical chemistry.

**Table 5**. Student learning motivation as the implementation of guided inquiry-based learning resources in Cation Analysis teaching.

| No | Indicator | Description of learning motivation | Respondents‘ optinions* (*n*=30) |
|---|---|---|---|
| 1 | Confidence | Student confidence in using innovative learning resources for independent active learning and conducting inquiry tasks. | 4.20±1.06 |
| 2 | Challenge | The suitability of the challenge on the inquiry task with the Cation Analysis material being studied. | 4.33±0.84 |
| 3 | Engagement | Availability of teaching materials, examples of inquiry, multimedia, and templates to guide students in active learning in completing inquiry tasks independently. | 4.40±0.81 |
| 4 | Curiosity | Students' curiosity in finding the best qualitative analysis method for contextual determination of cations in real samples. | 4.23±0.7 |
| 5 | Relevance | Availability and suitability of teaching materials and inquiry assignments in learning resources with the needs of students studying cation analysis. | 4.30±0.79 |
| 6 | Satisfication | The level of student satisfaction in using learning resources on the achievement of competence in the | 4.60±0.72 |

| | | |
|---|---|---|
| | analytical field. | |
| Average | | 4.34±0.83 |

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

## 4 Discussion

Analytical chemistry as a compulsory subject for undergraduate students in the Department of Chemistry plays a very important role in building student competence in the analytical field, including separation, identification and determination of qualitative or quantitative [15,16]. Analytical skills must be practiced contextually carried out in the laboratory [17]. Global problems due to the Covid-19 pandemic have forced the implementation of learning to be carried out online to break the transmission of the corona virus, resulting in the teaching of Analytical Chemistry not being carried out holistically, and minus practices that build analytical skills in the laboratory [18,19]. The application of inquiry-based learning in this study is a blended learning model, a combination of online and face-to-face which is designed to facilitate independent active learning to achieve competence in the field of qualitative analytics. Inquiry-based learning resources developed for the subject of Cation Analysis have been systematically, complete, and digitally based to meet the needs of learning resources for undegraduate students [20]. The learning resources resulting from these innovations are standard based on expert opinion, and have the advantage of guiding students to achieve target competencies. The eligibility criteria for learning resources have been met in terms of content breadth, completeness, accuracy, design, and language [21,22]. The availability of innovative learning resources is an advantage in directing students to actively carry out their inquiry tasks during abnormal times due to the Covid-19 pandemic

The implementation of inquiry-based innovative learning resources in the teaching of Analytical Chemistry has been proven to be effective in building thinking skills, especially the HOTS category, as a strategy to teach students knowledge and skills in the field of qualitative analysis [23,24]. Innovative learning resources integrated with inquiry tasks have succeeded in helping students learn Cation Analysis. Competence in the field of cation analysis has been achieved as indicated by high achievements in the field of analytical chemistry skills and knowledge. The three thinking skills in the HOTS category have been achieved because students are systematically given the challenge of conducting inquiry activities according to the subject being studied [25,26]. Inquiry activities have helped students think analytically in solving qualitative determination problems. Analytical skills have led students to systematically carry out analytical steps in answering the question of what target analyte is in the sample through the following stages: sample treatment, determining the appropriate precipitating compound, separating cations, identifying and confirming the presence of analytes using chemical reactions. Evaluate thinking is also built through inquiry assignments, where students can evaluate the effectiveness of qualitative determination, especially assessing the effectiveness of the method chosen for qualitative determination. The steps taken are considering several precipitating compounds that can selectively separate the target analyte, and the determination of specific reagents that can correctly identify the target compound. For the success of qualitative analysis of cation determination, students develop creative skills, namely determining good strategies in implementing new cation analysis methods in qualitative determination.

The learning resource package and its supporting facilities guide and motivate students to study actively, carry out inquiry tasks correctly, and solve problems in the field of cation analysis. Inquiry learning is very appropriate to be implemented in teaching chemistry because it can promote analytical thinking, practice critical thinking in evaluating qualitative determination activities, and encourage new thinking in determining cations in the target sample. The inquiry step requires systematic scientific thinking in the HOTS category, starting from asking questions, identifying problems, researching, reporting investigation results, and sharing finding information [27,28]. All of these steps make students directly involved in learning, and ultimately increase knowledge and skills that can be implemented in analysis in solving qualitative determination problems in real life. The availability of guided inquiry-based innovative learning resources has been proven to be effective in bringing students to think critically in problem solving, and has succeeded in improving learning outcomes. This learning model has motivated students to actively study analytical chemistry, and optimize their learning styles independently to achieve competence in the field of analytical chemistry [29-31]. This learning model can be applied to other courses that require increased knowledge and skills, and can be implemented in normal or abnormal situations as a strategy for achieving competence.

## 5 Conclusion

The guided inquiry model as part of active learning can guide students to carry out systematic investigations. Inquiry-based innovative learning resources have been successfully developed for the teaching of Analytical Chemistry. Learning resources have been implemented in the teaching of Cation Analysis, and are useful to facilitate students' active learning to conduct investigations. The inquiry stage starts from asking questions, conducting an investigation, reporting the results of the investigation, and finally sharing information on the findings of the qualitative determination. Higher order thinking skills in three aspects of skills such as analyzing, evaluating and creativity for the inquiry activity plan (M=80.51±4.32) and inquiry reports (M=85.07±1.70) are classified as good and very good. Students' knowledge in Cation Analysis is very good (M=83.16±4.82). Student competence in analytical field has been achieved for both qualitative chemistry skills and knowledge. The availability of innovative guided inquiry-based learning resources is a good strategy in facilitating students in achieving competence in the field of analytical chemistry, and can be implemented in normal situations and abnormal conditions caused by restrictions on access to work in laboratories during the Covid-19 pandemic.

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