Review challenges and constraints of project-based learning in chemical instrumentation to enhance competence and life skills

A T Prasetya*, S Haryani2, E Cahyono2 and Sudarmin2

1 Doctoral Degree of Postgraduate, Universitas Negeri Semarang, Indonesia, Kampus Kelud-Petompom-Gajah Mungkur Semarang Indonesia 50237
2 Chemistry Department, Faculty of Mathematics and Natural Science, Universitas Negeri Semarang, Indonesia, Sekaran Gunungpati Semarang Indonesia 50229

*Corresponding author: agungchem@mail.unnes.ac.id

Abstract. This article contains a review of research results (2008-2018) on project-based learning in science, especially in chemistry learning. Project-based learning is most appropriately applied to enhance critical thinking and creative skills in high learning. The result of a review of project-based learning in science and non-science learning has been discussed, project-based learning in chemistry and discourse apply project-based learning in chemical instrumentation. There are many challenges and obstacles to overcome so that project-based learning in instrumentation chemistry runs smoothly. At the end of the section, we described the benefits to be gained if project-based learning is applied in chemical instrumentation, which will increase competence through mastery of trace analysis methods and life skills through increased time management, responsibility, problem-solving, self-direction, collaboration, communication, creativity, and work ethic. The author also provides an overview of project completion on factors that can increase or decrease the success of project-based learning in instrumentation chemistry, and suggest further research directions.

1. Introduction
Graduated from Chemistry Study Program, FMIPA Universitas Negeri Semarang does not have the competence and life skills that are in accordance with the expectations as stated in the vision and mission of graduates who excel in chemistry and master information technology, honest, intelligent, open, skilled, independent, responsive to change, following the progress of science and the problems faced by society especially related to chemistry. Competence in analytical chemistry referred to as the trace analysis skill using modern instrumentation which includes sampling methods, preparation, measurement, and validation. The Life Skills in question is the ability to solve problems in the field of chemistry that can be encountered in everyday life (real world). The further consequence of the condition of graduates of chemistry with low competence and life skills is that they are difficult to compete in the global era due to the lack of authentic experience gained during lectures [1].

Increasing the competence and life skills of chemical graduates will be difficult to obtain if the learning model used is still centered on lecturers who will cause passive students. Surely this paradigm must be changed by emphasizing student-centered learning. Student-centered learning models that can be applied in science learning (instrument analysis chemistry) that provide an authentic experience to students include discovery-based learning, inquiry-based learning, problem-based learning and project-based learning.
based learning[1]–[4]. Project-based learning as a suitable learning model is used to reform the learning model from lecturer-centered to student-centered. With project-based learning, students become more active, critical, creative and will gain authentic experience in solving real-world problems and are recommended as effective learning models to apply in colleges [3], [4].

2. Application of Project-based Learning in various Fields of Science

The disruption era is characterized by the use of information and communication technology in various life activities. Through technology will be able to connect between regions in various parts of the world without borders. The development of information and communication technology in this century certainly have an impact on the world of education. The learning process must adapt to the change, from the lecturer-centered learning process to being student-centered. The criteria required by graduates to face the globalization era are creativity and entrepreneurship, technology and media literacy, effective communication, problem-solving, critical thinking and cooperative ability [2].

The project-based learning model requires students to be active in completing project work, by providing students with a learning experience directly to solve problems in their daily life in groups. Project-based learning is a learning model that provides an opportunity for lecturers to manage classroom learning by involving project work[5]. Project work contains complex tasks based on questions and issues that are very challenging and require students to design, solve problems, make decisions, conduct investigations, and provide opportunities for students to work independently[6]. From the results of the review of journal articles obtained information on the benefits of project-based learning in improving learning outcomes, as listed in Table 1.

| No | Learning outcomes                          | Reference |
|----|-------------------------------------------|-----------|
| 1  | Increase motivation to learn               | [4], [7]–[10] |
| 2  | Increase interest in learning              | [11]      |
| 3  | Change attitudes                           | [12], [13] |
| 4  | Improve cognitive understanding            | [14]      |
| 5  | Increased sense of responsibility          | [4]       |
| 6  | Increasing independence                     | [7], [15] |
| 7  | Improve communication ability              | [4], [7]  |
| 8  | Improve cooperation                        | [7]–[9], [16] |
| 9  | Improve academic achievement               | [7], [10], [17] |
| 10 | Minimize misconceptions                    | [7]       |
| 11 | Improving the ability of scientific thinking | [1], [18] |
| 12 | Improve critical thinking skills           | [7], [8], [11], [19] |
| 13 | Improve the ability of creative thinking   | [4], [11], [20] |
| 14 | Improving the skills of the science process | [12]      |
| 15 | Provide authentic experience               | [1]       |
| 16 | Improve life skills                        | [4]       |
| 17 | Increased preparedness in facing the world of work | [21] |

Table 1. Increasing learning outcomes through project-based learning

Based on the result of article reviews, project-based learning is considered a perfect approach to be applied in the field of science (chemistry). The project-based learning model will help students to think scientifically (critical and creative thinking) in solving problems in everyday life with complex communicative cooperation through the activities of preparing hypotheses, collecting, processing data/information to test hypotheses and make decisions and conclusions. The project-based learning model will give students an authentic experience to develop a true understanding of scientific work so that students can discover and build their inner knowledge to be more meaningful and durable [1].
3. Application of Project-based Learning in Chemical Field

Implementation of project-based learning in the field of chemistry can improve student learning outcomes. The results of a number of scientific articles in the field of chemistry obtained information on improving learning outcomes as listed in Table 2.

| No | Learning outcomes                      | Reference   |
|----|---------------------------------------|-------------|
| 1  | Increase motivation                    | [22], [23]  |
| 2  | Improve attitude                       | [22], [24]  |
| 3  | Increase interest in learning          | [22]        |
| 4  | Increased confidence                   | [25]        |
| 5  | Improve concept mastery                | [26]        |
| 6  | Improve academic achievement           | [24]        |
| 7  | Improve self-study capability          | [25], [27]  |
| 8  | Improve communication skills           | [23], [25]  |
| 9  | Improve cooperation                    | [23]        |
| 10 | Improving the skills of the science process | [22] |
| 11 | Improve critical thinking skills       | [25], [27]  |
| 12 | Improve the ability of creative thinking | [2]    |
| 13 | Provide an authentic experience        | [2]         |
| 14 | Reduce the level of anxiety            | [22], [28]  |
| 15 | Reduce misconceptions                  | [29]        |

Project-based learning is applicable in many chemical fields such as in physics chemistry to explore sol-gel synthesis [30], in analytical chemistry for acid-base titration material [31], in organic chemistry for the discussion of pesticide separation in drinking water [32], as well as in chemical education to see students' anxiety levels as prospective teachers [28]. The results of the review of the articles from the educational journals show that the use of project-based learning in chemistry is very diverse, but when viewed in more detail from the point of view of the use of chemical instrumentation looks very limited in the field of conventional instrument chemistry and has not been touched in modern instrumental chemistry. The study that has been revealed in an article with project-based learning that bridges between conventional instruments and modern instruments are through virtual lab media. Through virtual lab, media combined with project-based learning, can enhance self-confidence, enhance conceptual understanding and can relate to the relationship between modern chemical theory and practice [33], and can minimize misconceptions in instrumentation chemistry [29].

The results of several years of observation on the implementation of active learning project-based learning in chemistry laboratory obtained information in the form of challenges that must be handled for the project-based learning run smoothly and successfully, the lack of funds for accommodation and travel to the field, students difficulties in tracking the scientific literature, students difficulties in translating and interpreting scientific literature into experimental steps, the limited access to instrumentation laboratories, as well as difficulties in operating instruments, students have difficulties in calculating, preparing experimental reports. The issues that will be revealed are how to handle the challenges of implementing chemistry learning instrumentation through project-based learning to improve students' competence and life skills through authentic experience [25].

4. Discussion on Application of Project-based Learning in Chemical Instrumentation Field

Implementation of chemistry learning instrumentation using project-based learning is very difficult to do well because many obstacles and challenges that must be overcome. I am a lecturer of instrumentation chemistry who has taught modern instrumentation material for many years felt deeply convinced that project-based learning can be well executed for instrumentation chemistry, through the reduction of obstacles and challenges that have been presented by Cavinato [25]. In order for the learning of instrumentation chemistry through project-based learning to work properly, the challenges that arise...
must be eliminated. First, the problem of lack of funds for accommodation and travel during the completion of the project can be reduced by determining the location of the project as a place of learning around the campus, the location can be either an artificial lake or river basin around the campus. By taking the location of the project around the campus, then no more accommodation and travel costs.

Second, difficulties in finding and translating scientific literature can be overcome by providing easy access to the internet and computing laboratories on campus. Internet access in computing labs is very fast and can browse to free journal sites and journals that have been subscribed by the campus for free.

Third, the need to add instructors to assist students in understanding the contents of the scientific literature obtained so that they are able to develop experimental work steps. The instructor may come from a junior professor, a laboratory technician or an assistant.

Fourth, the difficulty in instrument operation and calculation can be overcome by providing assistance through highly trained technicians and assistants. By doing cooperation and communication in the group and write every activity in the journal, lessons become more effective and difficulties in preparing report can be minimized. Through the application of learning chemistry instrumentation with project-based will be able to run smoothly and can improve the competence and life skills will emerge during the learning process. This belief emerged not without reason, but arises in response to the reform of the learning system from the learner-centered learning model to innovative student-centered learning and emphasizes contextual learning through authentic experience.

The full picture to address the challenges in project-based learning in instrument analysis is summarized in Figure 1.

---

**Figure 1. Learning of project-based instrumental analysis**

Project work is seen as a form of open-ended contextual activity-based learning and is part of a learning process that places a strong emphasis on problem-solving as a collaborative effort, conducted in a learning process over a period of time. Project work contains complex tasks based on challenging statements and issues and requires students to design, solve problems, make decisions, conduct investigatory activities, and provide them with the opportunity to work independently or in groups. From project-based learning, students will gain more meaningful and interesting knowledge, because the knowledge gained becomes more useful for themselves in appreciating the environment, understanding and solving problems encountered in everyday life. The further effect of project-based learning is to increase students' motivation and creativity [26].

The reviewer has a view that the competence and life skills of students can be obtained through project work. The first step is to divide the students into small groups of 2-3 students. The goal is that the learning process can run effectively and every member of the group can work optimally and easily to be observed in the learning process. In order to reduce the cost of project work, the division of working groups has been considered on the basis of the interest of the students, namely specialization in physics chemistry, analytical chemistry, organic chemistry or physical chemistry. Each group will get a different project in accordance with its specialization. As an illustration, students who are interested in analytical...
chemistry will get a project work designed by their solving path using UV-Vis (ultraviolet-visible) spectrophotometer, AAS (Atomic Absorption Spectrophotometer) or ICP-OES (Inductively Coupled Plasma Optical Emission Spectrometer). Students who are interested in organic chemistry will get a project work that completes the path using GC (Gas Chromatography), HPLC (High-Performance Liquid Chromatography) or FT-IR (Fourier Transform Infrared), and students interested in physical chemistry will get project work the completion path using the PSA (Particle Size Analyzer) and SAA (Surface Area Analyzer) instruments, and so on [34]. The grouping of students in this area of interest is expected to lower the operational costs of the project. The weakness that arises from this method is that students can not learn all kinds of modern instrumentation in their learning. this weakness can be eliminated by giving each group a chance to present the project work in detail so that all students will still be able to learn about modern instrumentation even if they do not use the instrument during project completion.

Project work that can be raised in the field of analytical chemistry such as analysis and speciation of heavy metal contamination, in organic chemistry can be separation and analysis of pesticides, and in the field of physical chemistry can be heavy metal adsorption method with various adsorbents such as clay, carbon, zeolite, bentonite very abundant as well as the activation process with samples originating from artificial lakes or watersheds around the campus. The theme described can be obtained around the campus so as to minimize the use of funds during project work outside the laboratory. A complete description of the interrelationships between themes as shown in Figure 2.

Figure 2. The interrelationship between themes in project work

Steps in project-based learning that needs to be done so that the project can run according to the objectives include:

1. activities begin with open and complex questions and cannot be answered simply by students. Each group should design activities to answer such questions or issues through scientific work
2. the student must have initial knowledge that has been obtained in the previous course so that through the literature study can collect information and answer questions or problems
3. students must use critical thinking skills to develop hypotheses or develop procedures for solving problems and to list the chemicals to be used while maintaining occupational safety at the laboratory
4. when the experiment is carried out, the student must make a decision about the design or design that they choose including determining factors to be varied or controlled while taking into account the security aspect
5. students should be able to ensure the modern tools and instruments to be used in accordance with the parameters to be investigated
6. students should be able to use appropriate methods to validate the measurements they choose including repetition in measurements
7. students should be able to process information collected or provided and analyzed (eg explaining, tabulating, summarizing, counting, tables, graphs, diagrams)
8. students should be able to draw conclusions from information gathered or provided and support their conclusions
9. students should be able to report their findings in the form of written reports and presentations.

In order for the steps in project-based learning to be recorded, recorded and organized well then the students individually and group to always write the activity journal. By writing activity journals, it allows students to be responsible for the learning process on their own. Writing activity journals will assist students in developing writing skills and improve communication skills in scientific activities as well as helping students understand how real-world problems can be solved as scientists regularly write daily activity journals as a means of understanding their thought processes. Writing activity journals will also develop students' ability to reflect on their own thought processes. The contents of the journal activities that should be written by the students during the activities in completing the project include scientific observation, thought / reflection on the observation, exploration of ideas, questions, thoughts, data collected in the experiment, the relationship between the observed data with the concept of knowledge learned, in the form of data, labeled graphs, graph data, images, photos, diagrams, comments and reflections.

5. Conclusion
In each project work theme will be performed competence and life skills of each student who can be observed through various sources of data, either through tests, interviews, and observations during the completion of the project work. Competence in trace analysis skill can be seen from sampling and preparation method and from hypothesis and data collection method, using modern instrument and validation of analysis method including accuracy, precision, correlation, linearity and determination of limit of detection and quantization limit. Life skills in the field of chemistry can be observed during work on projects that include time management, responsibility, problem solving, self-direction, collaboration, communication, creativity, and ethical work in solving problems in the field of chemistry encountered in everyday life through hypothesis submission, collecting data, interpreting collected data, predicting results, drawing conclusions and presenting results.

References
[1] Baumgartner E, and Zabin C J 2008 Environ. Educ. Res. 14 (2) 97–114
[2] Frederick K A 2013 Anal. Bioanal. Chem. 405 (17) 5623–5626
[3] Lee J S, Blackwell S, Drake J, and Moran K A 2014 Interdiscip. J. Probl. Learn. 8 (2) 18–34
[4] Wurdinger S and Qureshi M 2015 Innov. High. Educ. 40 (3) 279–286
[5] Morgil I, Seyhan H G, and Secken N 2009 J. Turkish Sci. Educ. 6 (1) 108–114
[6] Sumarni W 2013 Int. J. Sci. Res. 4 (3): 478–484.
[7] Bagheri M, Ali W Z W, Chong M B A, and Daud S M 2013 Contemp. Educ. Technol. 4 (1) 15–29
[8] Chandrasekaran S, Stojcevski A, Littlefair G, and Joordens M 2012 in SEFI 40Th Annual Conference March 1–8
[9] Elam J R and Nesbit B 2012 JALTCALL J. 8 (2) 113–127
[10] Hung C M, Hwang G J, and Huang I 2012 J. Educ. Technol. Soc. 5 (4) 368–379
[11] Chun M S, Il Kang K, Kim Y H, and Kim Y M 2015 Univers. J. Educ. Res. 3 (11) 937–942
[12] Ergül R, Simsekli Y, Calis S, Ozdilek Z, Gocmencelebi S, and Sanlı M 2011 Bulg. J. Sci. Educ. Policy 5 (1) 48–68
[13] Yalçın S A, Turgut Ü, and Büyükasap E 2009 Int. Online J. Educ. Sci. 1 (1) 81–105
[14] Johnson C S and Delawsky S 2013 Acad. Res. Int. 4 (4) 560–570
[15] Jumaat N F and Tasir Z 2013 Procedia - Soc. Behav. Sci. 103 526–533
[16] Ergül N R and Kargın E K 2014 Procedia - Soc. Behav. Sci. 136 537–541
[17] Baş G and Beyhan Ö 2010 Int. Electron. J. Elem. Educ. 2 (3) 365–385
[18] Kubiatko M and Vaculová I 2011 *Energy Educ. Sci. Technol. Part B Soc. Educ. Stud.* 3 (1) 65–74
[19] Eskrootchi R and Oskrochi G R 2010 *Educ. Technol. Soc.* 13 (1) 236–245
[20] Mihardi S, Harahap M B, and Sani R A 2013 *J. Educ. Pract.* 4 (25) 188–200
[21] Jollands M, Jolly L, and Molyneaux T 2012 *Project Based Learning as a Contributing Factor to Graduates’ Work Readiness*
[22] Morgil I, Seyhan H G, Alsan E U, and Temel S 2008 *Turkish Online J. Distance Educ.* 9 (2) 220–237
[23] Robinson J K 2013 *Anal. Bioanal. Chem.* 405 (1) 7–13
[24] Su K D 2008 *Int. J. Sci. Math. Educ.* 6 (2) 225–249
[25] Cavinato A G 2017 *Anal. Bioanal. Chem.* 409 (6) 1465–1470
[26] Chairam S, Klahan N, and Coll R K 2015 *Eurasia J. Math. Sci. Technol. Educ.* 11 (5) 937–956
[27] Fatokun J O and Fatokun K V F 2013 *Educ. Res. Rev.* 8 (11) 663–667
[28] Erdem E 2012 *World Appl. Sci. J.* 17 (6) 764–769
[29] Carbó A D, Adelantado V J G, and Reig F B 2010 *US-China Educ. Rev.* 7 (7) 15–29
[30] Santos D M D L, Montes A, Coronilla A S, and Navas J 2014 *J. Chem. Educ.* 91 (9) 1481–1485
[31] Tarhan L and Acar-Sesen B 2013 *J. Balt. Sci. Educ.* 12 (5) 565–578
[32] O’Hara P B, Sanborn J A, and Howard M 1999 *J. Chem. Educ.* 76 (12) 1673–1677
[33] Limniou M, Papadopoulos N, and Roberts D 2007 *Educ. Inf. Technol.* 12 (4) 229–244
[34] Zhang S and Zhang X 2014 *Anal. Bioanal. Chem.* 406 (17) 4005–4008