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INOVAÇÃO DE APRENDIZAGEM DO TRABALHO DE LABORATÓRIO DE ANÁLISE INSTRUMENTAL PARA MELHORAR O NOVO LETRAMENTO DOS ALUNOS E A MOTIVAÇÃO DE APRENDIZAGEM NA PANDEMIA DO COVID-19

LEARNING INNOVATION OF INSTRUMENTAL ANALYSIS LAB WORK FOR IMPROVING STUDENTS' NEW LITERACIES AND LEARNING MOTIVATION IN THE COVID-19 PANDEMIC

INOVASI PEMBELAJARAN PRAKTIKUM KIMIA ANALISIS INSTRUMEN DI MASA PANDEMI COVID-19 UNTUK MENINGKATKAN LITERASI BARU DAN MOTIVASI BELAJAR

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RESUMO

Introdução: O surto de COVID-19 mudou drasticamente a educação. O ensino e a aprendizagem são realizados à distância e em plataformas digitais. Portanto, a inovação na aprendizagem precisa ser realizada para manter e manter os objetivos de aprendizagem. Infelizmente, alguns cursos são desafiadores para serem realizados remotamente, como o trabalho de laboratório de análise instrumental. Este trabalho de laboratório químico envolve o uso de instrumentação analítica moderna, como HPLC, AAS e GC. **Objetivo:** Neste estudo, foi realizada a inovação de um modelo de aprendizagem online de laboratório de análise instrumental para alunos de química. A inovação tem como objetivo proporcionar experiências autênticas e motivacionais para os alunos enquanto aprendem remotamente. **Métodos:** A primeira inovação foi realizada por meio de experimentos de verificação usando um medidor de pH virtual interativo e um espectrofotômetro visível. A segunda foi realizada com a concepção de um experimento criativo baseado em projeto. O experimento determinou a concentração de soluções coloridas utilizando câmeras digitais ou smartphones e software de análise de imagem colorida como um substituto para um espectrofotômetro visível. A implementação de experimentos com mídias virtuais interativas teve como objetivo introduzir diversas instrumentações analíticas. Além disso, também treinou os alunos no processamento e interpretação de dados experimentais. Enquanto isso, os experimentos baseados em projetos tinham como objetivo treinar os alunos a projetar e aplicar um experimento, em seguida, analisar e relatar os resultados de forma criativa. **Resultados e Discussão:** A avaliação autêntica resultou em literacia em dados, literacia tecnológica e literacia humana com critérios alto e muito alto, nomeadamente 89%, 95% e 95%, respectivamente. Enquanto isso, as habilidades dos alunos na concepção de projetos e no processamento de dados precisam ser melhoradas. **Conclusões:** Em geral, é comprovado que a inovação de aprendizagem desenvolvida aumenta a motivação de aprendizagem de todos os alunos.

Palavras-chave: *Trabalho de Laboratório; Análise Instrumental; Literacia de Dados; Alfabetização Tecnológica; Alfabetização Humana; Motivação de Aprendizagem*

ABSTRACT

Background: The COVID-19 outbreak has changed education dramatically. Teaching and learning are undertaken remotely and on digital platforms. Therefore, learning innovation needs to be carried out to keep and maintain the learning objectives. Unfortunately, some courses are challenging to carry out remotely, such as Instrumental analysis labwork. This chemistry labwork involves using modern analytical instrumentation, such as HPLC, AAS, and GC. **Aim:** In this study, an innovation of an online learning model of instrumental analysis labwork for chemistry students was carried out. The innovation aims to provide authentic and motivational experiences for students while learning remotely. **Methods:** The first innovation was carried out by verification experiments using an interactive virtual pH meter and visible spectrophotometer. The second was carried out by designing a creative project-based experiment. The experiment determined the concentration of colored solutions

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by utilizing digital cameras or smartphones and color image analysis software as a substitute for a visible spectrophotometer. The implementation of experiments with interactive virtual media was intended to introduce various analytical instrumentations. In addition, this also trained the students in processing and interpreting experimental data. Meanwhile, the project-based experiments were intended to prepare students to design and apply an experiment, then analyze and report the results creatively. **Results and Discussion**: The authentic assessment resulted in data literacy, technological literacy, and human literacy having high and very high criteria, namely 89%, 95%, and 95%, respectively. Meanwhile, students' abilities in designing projects and processing data need to be improved. **Conclusions:** In general, the learning innovation developed is proven to increase the learning motivation of all students.

Keyword: *Lab Work; Instrumental Analysis; Data Literacy; Technological Literacy; Human Literacy; Learning Motivation*

ABSTRAK

Latar Belakang: Wabah COVID-19 telah mengubah pendidikan secara dramatis. Pengajaran dan pembelajaran dilakukan dari jarak jauh dan melalui platform digital. Oleh karena itu, inovasi pembelajaran perlu dilakukan untuk menjaga pencapaian tujuan pembelajaran. Sayangnya, beberapa mata kuliah sulit untuk dilakukan dari jarak jauh, seperti Praktikum Kimia Analisis Instrumen. Praktikum Kimia Analisis Instrumen ini menggunakan instrumentasi analitik modern, seperti HPLC, AAS, dan GC. **Tujuan:** Pada penelitian ini dilakukan inovasi model pembelajaran online Kimia Analisis Instrumen untuk mahasiswa kimia. Inovasi tersebut bertujuan untuk memberikan pengalaman otentik dan motivasi bagi mahasiswa saat belajar secara luring. **Metode:** Inovasi pertama dilakukan dengan praktikum verifikatif menggunakan media virtual interaktif berupa pH-meter dan spektrofotometer sinar tampak. Inovasi kedua dilakukan dengan merancang praktikum berbasis proyek. Pada praktikum berbasis proyek, penentuan konsentrasi larutan berwarna dengan memanfaatkan kamera digital atau smartphone dan perangkat lunak analisis citra warna sebagai pengganti spektrofotometer sinar tampak dilakukan. Pelaksanaan praktikum dengan media virtual interaktif ini dimaksudkan untuk memperkenalkan berbagai instrumentasi analitik. Selain itu juga melatih mahasiswa dalam mengolah dan menginterpretasikan data eksperimen. Praktikum berbasis proyek dimaksudkan untuk melatih mahasiswa dalam merancang dan melakukan eksperimen, menganalisis, dan melaporkan hasilnya secara kreatif. **Hasil dan Diskusi:** Penilaian otentik menghasilkan literasi data, literasi teknologi, dan literasi manusia dengan kriteria tinggi dan sangat tinggi, yaitu sebesar 89, 95, dan 95%. Kemampuan mahasiswa dalam merancang proyek dan mengolah data masih perlu ditingkatkan. **Kesimpulan:** Secara umum inovasi pembelajaran yang dikembangkan terbukti mampu meningkatkan motivasi belajar seluruh mahasiswa.

Kata kunci: Praktikum; Analisis Instrumentasi, Literasi Data, Literasi Teknologi, Literasi Manusia, Motivasi Belajar

1. INTRODUCTION:

Higher education institutions must reform their education system to maintain graduates with 21st-century competencies (Cavinato, 2017). Graduate competencies are designed to be achieved through a direct (face-to-face) learning system in the classrooms, studios, or laboratories. However, the Covid-19 that hit globally caused the classroom activities to adapt to new types of learning, fully online learning. Moving from offline to online learning is not easy, especially for chemistry lab-based courses. One of the courses is instrumental analysis labwork. This wet-chemistry labwork involves using modern and bulky analytical instrumentation, such as HPLC, GC, AAS, and UV-Vis spectrophotometer (Boivin and Welby, 2021; Munday, 2021).

Lecturers have to design and prepare experiments that allow being carried out online and remotely. Innovation and creativity are needed to design such experiments. At the beginning of the pandemic, instrumental analysis lab work was carried out using two methods. 1) students were given experimental data, then asked to process the data and submit a report, 2) students were given videos of an experimental process completed with the data, then asked to process and interpret the data and submit a report. This model was far from ideal. Ideally, students must follow the scientific method steps to get scientific truth. They have to be experienced with 1) setting the problem, 2) conducting theoretical studies and drawing hypotheses, 3) conducting experiments or observations, 4) processing observational data, and 5) concluding (Aktamis and Ergin, 2008; Jiang, 2005).

Therefore, a learning model that requires students to be active, creative, innovative, and communicative and apply critical thinking skills is needed. Project-based Learning (PBL) is one of the models that require students to apply those skills. In PBL, students are given complex tasks with challenging questions and problems. Moreover, it requires students to design and conduct an investigation, make decisions and solve problems. This model also provides opportunities for students to work independently or in a group (Sumarni, 2013). The PBL model will strengthen and broaden students' knowledge horizons. The knowledge gained by students during the experiment becomes meaningful because it can be applied to understand and solve problems in life. Thus, students' creativity and learning motivation will increase (Bagheri *et al*., 2013; Malawati and Sahyar, 2016).

The PBL model can increase learning motivation, critical thinking, and creativity, as well as academic achievement (Akinoglu and Tandogan, 2007; Bagheri *et al*., 2013; Baş and Beyhan, 2010; Chun *et al*., 2015; Frederick, 2013; Robinson, 2013; Wurdinger and Qureshi, 2015). The PBL model can also provide authentic experiences for students in developing their skills in everyday life problem-solving. The problem-solving is carried out through a scientific approach, collaborating and communicating in teams, as well as interpreting data, predicting results, and drawing conclusions (Bagheri *et al*., 2013; Cavinato, 2017; Frederick, 2013; Jollands *et al*., 2012; Wurdinger and Qureshi, 2015). Chemistry graduates need these authentic experiences to compete in the real world (Baumgartner and Zabin, 2008; Jollands *et al*., 2012; Wurdinger and Qureshi, 2015). The PBL can motivate students to work at the highest level of performance with the following criteria: 1) problems must be complex, authentic, interesting, and real, so students are required to work hard to produce high-quality data and communicate their findings effectively, 2) problems must be open, this will make students look for different problem-solving methods in completing projects, 3) at the end of the project, students are required to make a report (Robinson, 2013).

This report presents an innovation of online Instrumental analysis labwork that is applicable in the covid-19 pandemic era. The innovation is expected to keep and maintain graduate competencies while the learning is carried out online. Here, innovation was designed and implemented to correctly construct concepts, laws, or principles in analytical methods with various chemical instruments.

The purpose of this study is to find an online Instrumental Analysis Labwork model that can measure the level of knowledge and skills of chemical analysis, the level of new literacy (technological literacy, data literacy, and human literacy), and student motivation to learn.

2. MATERIALS AND METHODS:

2.1 Data Collecting Instruments

An innovation of the learning model of instrumental analysis labwork for chemistry students has been implemented. The implementation was conducted by a one-group pretest-posttest design in 2 classes with 67 students (13 male and 54 female) for 16 meetings (Creswell, 2010). In semester 5 of the Department of Chemistry Faculty of Mathematics and Natural Sciences, Universitas Negeri Semarang, Central Java, Indonesia, the students were undergraduate chemistry students. All students participating in this study have agreed to be involved, and this does not affect their final grades in the course

The experimental innovation consists of two categories (Appendix 1). The first is verification experiments (experiment 1-5) using an interactive virtual pH meter and visible spectrophotometer. The virtual pH-meter was used interactively to determine the weak acid equilibrium constant (Ka). The virtually visible spectrophotometer was used in an experiment to determine the maximum wavelength of complex compounds, calibration curves, limits of detection (LoD), and quantization (LoQ) and to simulate the determination of analyte concentrations. The second category was designed as a project-based experiment (experiment 6). Students were required to design an experiment using their camera or smartphone and image analysis freeware to analyze colored compound solutions quantitatively.

Individual assignments were given online, including verificative virtual experiments, discussions, report submission, and project-based experiments through a moodle-based LMS (elena.unnes.ac.id). All authentic assessment instruments used in the study have been validated by learning experts (Prof. Dr Anna Permanasari, M.Si from Universitas Pendidikan Indonesia and Prof. Dr Sudarmin, M.Si from Universitas Negeri Semarang) and evaluation experts (Prof. Dr Isti Hidayah, M.Si and Dr Saiful Ridlo, M.Si, both are from Universitas Negeri Semarang).

Data literacy and learning motivation of the students were assessed with the following conditions.

a. The level of data literacy was assessed by 18 indicators (questions/statements) which are divided into three parameters (Appendix 2), namely:
    1. ability to process pH data of a solution (weak acid, buffer) to calculate the weak acid equilibrium constant (Ka),
    2. ability to process wavelength and absorbance data to create a calibration curve, calculate LoD and LoQ,
    3. Ability to process photos into color image data, determine the linearity of the color image (RBG) with color intensity, create a calibration curve, and determine the concentration of colored solutions.
b. The level of technological literacy was assessed by 19 indicators (questions/ statements) which were divided into three parameters (Appendix 3), namely:
    1. ability to use interactive software to obtain experimental data
    2. ability to report testing results
    3. ability to prepare equipment for a project-based experiment as shown in Figure 1.
c. The level of human literacy was assessed by 23 indicators (questions/statements) which were divided into two parameters (Appendix 4), namely:
    1. ability to conclude verification experiments
    2. ability to compile, design, and report the results of a project-based experiment.
d. The level of student learning motivation was measured using a Likert scale which consisted of 25 indicators (questions/ statements) and was divided into five parameters (Appendix 5).

2.2 Data Analysis

Authentic assessment data are grouped according to their classification. Using a Likert scale authentic assessment rubric, the level of data literacy, technological literacy, human literacy, and student motivation were measured (Hake, 2008).

3. RESULTS AND DISCUSSION:

In the industrial revolution 4.0 era, universities must equip their graduates with new literacies: data, technology, and human literacy. Students must be able to process and interpret data, as well as understand and utilize technology well. Moreover, human literacy is needed so that students understand their interactions as human beings. Therefore, universities need to formulate learning models to develop these new higher-order thinking and literacy skills (Bortnik *et al*., 2017; Munday, 2021; Prasetya *et al*., 2019)

The COVID-19 pandemic has disrupted the learning process throughout the education system. As a result, there is a change in the learning process, from face-to-face learning in the classroom to online learning. As a result, many problems arise, including the learning models and online platform used and the availability of supporting infrastructures such as laptops/PCs, smartphones, and internet networks. More complex problems arise in the online Instrumental analysis labwork because students cannot conduct experiments from home. Therefore, it is necessary to design a breakthrough in a learning model that can bridge the existing problems. Thus, the learning process can continue well, and the students' competencies are achieved (Boivin and Welby, 2021).

The implementation of the innovation model on instrumental analysis labwork has had an excellent effect. Firstly, we investigate the new literacies level of students who participated in the course. The data literacy, technological literacy, and human literacy levels showed high and very high criteria of 89, 95, and 95%, respectively (Figure 2).

A more detailed recapitulation of the new literacies level in each parameter was presented in Table 1. For data literacy, only 21% of the students could convert the intensity of RBG color images to the concentration of colored solutions in the high category. Thus, it needs to be improved. Meanwhile, in technological and human literacies, most of the parameters observed were in high criteria.

3.1 Data Literacy

The students' ability for data literacy can be observed from the ability of students to read, classify, process, and analyze the experimental data. In the verification experiments (experiments 1-5, appendix 5), students have gained experience accessing, completing, and uploading assignments and operating various analytical instrument software. In the experiments, students were required to run a virtual pH meter and visible spectrophotometer software and collect experimental data according to the method provided in the manual book (Usova and Laws, 2021). From the collected data, students were required to calculate the Ka of acetic acid (experiment 1), determine the maximum wavelength of a complex compound solution (experiment 2-3), create a calibration curve, and calculate the correlation coefficients (r^2), LoD, and LoQ (experiment 4-5).

In the experiment of determining the Ka of acetic acid, 56 students (84%) could convert experimental data to calculate the Ka of acetic acid very well. However, only 33 students (49%) have compared the obtained experimental data with the Ka value from references. In the experiment, the determination of Ka acetic acid was carried out in two ways: measuring the pH of a weak acid solution and a buffer solution. From the results, 84% of students correctly determined the Ka of acetic acid, indicating that students have been able to distinguish the relationship between pH and [H] in a weak acid and buffer solution (Yilmaz, 2019).

Determination of the maximum wavelength is essential in spectrophotometric analysis. According to Lambert-Beer law, this is done to obtain a linear relationship between absorbance and analyte concentration. In the experiment to determine the maximum wavelength of complex compounds (experiments 2-3), data were obtained that 56 students (84%) were able to make a curve of the wavelength versus absorbance relationship and correctly determine the maximum wavelength of the observed complex compounds. In practice, it was found that students measured the absorbance of the analyte from small to large wavelengths. It is not suitable because absorbance measurements are carried out from high energy levels to low energy levels. According to the equation $E = h.c/\lambda$, it is advisable to search for the maximum wavelength from low to high energy levels (Fakayode *et al*., 2014; Larive, 2004; Robinson, 2013).

Calibration curves for analysis must provide complete information, including data related to linearity ranges, correlation coefficients, LoD, and LoQ. Complete information will provide high confidence for readers. Students must be given an understanding that the results of instrumentation analysis are not always correct and valid. The analysis results need to be supported by other information: the linearity range, correlation coefficient, LoD, and LoQ. Through experiments 4-5, students are trained to analyze correctly and conclude whether the measurement results are valid/invalid. This experiment found that 55 students (82%) could make a calibration curve and calculate the correlation coefficient correctly. There were 50 students (75%) who had calculated their LoD and LoQ and decided whether the experimental results had met the valid/invalid criteria. Skills in making calibration curves still need to be improved through repeated experiments (Cesarino *et al*., 2018; Harmita, 2004; Jiang, 2005; Tek *et al*., 2012)

In a project-based experiment (experiment 6), students have already been trained in reading, classifying, utilizing, and analyzing data based on their level of validity. In this experiment, it was obtained that 64 students (96%) were able to process color intensity and RGB color image data and then convert it into a calibration curve. However, only 14 students (21%) had calculated LoD and LoQ from the obtained curves.

Overall, 60 students (89%) who participated in the lab work had data literacy levels at high and very high categories. There were four students (6%) in the medium category and three (5%) in the low category. Students with a common category of data literacy were not active in experimental activities.

3.2 Technology Literacy

In the verification experiments (experiment 1-5), the students technological literacy was assessed from the accuracy in completing and uploading assignments. Students were stated to have a high level of technological literacy if they could access the assignments through LMS and then complete and upload their works on time. This literacy was also assessed through the students' performance on using experimental software (Cavinato, 2017; Prasetya *et al*., 2020; Taylor *et al*., 2015).

In the verification experiment, 65 students (97%) can use experimental software very well and submit their labwork reports into the LMS. There are two students (3%) who are late in completing assignments. Meanwhile, for the project-based experiment (experiment 6), it was known that 63 students (94%) could assemble tools for the experiment according to the illustrations described in the guidebook and collect experimental data correctly. Sixty-three students could also choose RGB colour images to create a calibration curve and determine the sample concentrations. One example of a calibration curve that students have made is presented in Figure 3. It can be seen that students can choose a green calibration curve because it has the most significant correlation coefficient of 0.96. The calibration curve is then used to determine the concentration of the measured sample.

Overall, 64 students (96%) who participated in the instrumental analysis labwork had high and very high levels of technological literacy. Only one student (2%) in the medium category and two (3%) in the low category. Students whose level of technological literacy was low because they were not active in experimental activities.

Students participating in the instrumentation analysis course are very responsive in using information and communication technology. They are used to using smartphones and laptops in their daily lives. This experience has helped students in assembling equipment and applying information technology in learning. It proves that students already have technological literacy as a new literacy in the industrial revolution era (Haryani *et al*., 2010).

3.3 Human Literacy

The implementation of project-based experiments has trained students in designing projects. The authentic experience of students in completing this project can be used to measure the level of human literacy.

Human literacy data in the verification experiments were taken from students' ability to make valuable conclusions in their lab reports. There were 23 students (34%) who could draw the correct decisions to determine the acetic acid dissociation constant (Ka). Sixty students (90%) could get the correct conclusions in determining the maximum wavelength of complex compounds. There were 57 students (85%) who could correctly create and interpret the calibration curve, LoD, and LoQ.

In a project-based experiment, human literacy measurement was carried out by assessing project designs prepared by individual students. There were 62 students (93%) who could design projects very well. They can develop a project that consists of a title, purpose, background, apparatus and materials, and working procedure. There are two students whose their ability to prepare and design project was not good. Their designs were prepared in a non-standard format without stating the apparatus and materials and incomplete procedure.

In addition to having a standard format, a good project design must have specific goals, background according to the problem, be logical and be supported by appropriate literature. The ability of students to create backgrounds and search for literature still needs to be improved. It can be seen from the literature used in preparing project designs in experiment reports and textbooks. The literature referred to is minimal in the form of scientific articles. Students' mastery of information and communication technology has not been used optimally to support the learning process (Prasetya *et al*., 2020).

Overall, 64 students (96%) who took part in the labwork model had high and very high levels of human literacy. Three students (5%) were not active during the experiment, and hence they were in the low category of human literacy. Students who have a low level of human literacy are because these students are not active in experimental activities.

3.4 Learning Motivation

The level of student motivation to learn was measured using a questionnaire consisting of 25 questions/statements. This learning motivation questionnaire has been tested and declared valid (Prasetya and Ridlo, 2018). Learning motivation is influenced by several factors, namely intrinsic motivation, self-efficacy, self-determination, grade motivation, and career motivation. The five factors influence each other and determine the level of learning motivation. The measurement of the level of learning motivation was carried out online through Google form. There were 74% of students had a very high level of learning motivation, and 26% were in the high category.

In implementing the Instrumentation Analysis experiment in the previous period, students looked bored with the learning model. The innovation of the Instrumentation Analysis experimental model has been proven to increase learning motivation. It proves that implementing Instrumentation Analysis experiments conducted online using various interactive and creative software has kept students excited about learning. The complete data on the measurement of learning motivation is presented in Figure 4.

Intrinsic motivation factors contribute to the highest learning motivation, followed by career motivation and self-determination factors. The self-efficacy and grade motivation factors still need to be improved. There was a student who had a motivational grade in the medium category. Intrinsic motivation is a learning motivation factor that arises from within the students themselves. This motivation arose after conducting online analytical instrument labwork (Haryani *et al*., 2017; Prasetya and Ridlo, 2018).

4. CONCLUSIONS:

Innovation of an online analytical instrument labwork model can increase students' data, technology, and human literacies in the high and very high categories, 89%, 95%, and 95%, respectively. All students who were active during the activities have high and very high learning motivation. The intrinsic motivation factor was the most significant contributor to students' learning motivation. This innovation of the labwork model needs to be developed for other labwork courses.

5. DECLARATIONS:

5.1. Study Limitations

The authentic assessment was just done through project designs, reports, and questionnaires.

5.2. Acknowledgements

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5.4. Competing Interests

There are no conflicts of interest.

5.5. Open Access

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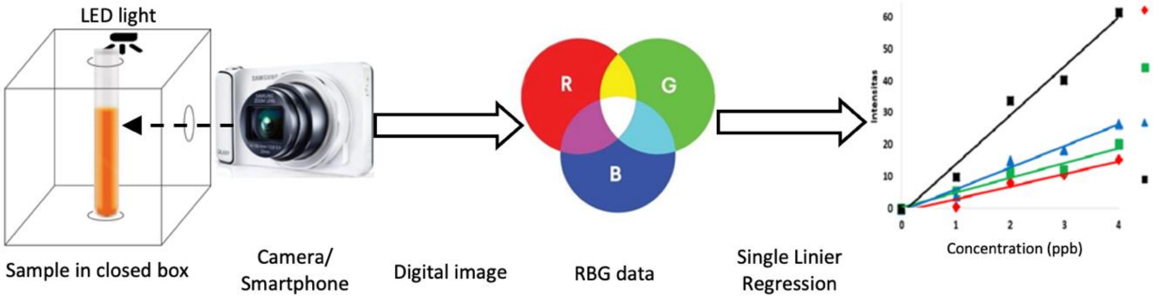

Figure 1. *Equipment and procedure in the analysis of coloured solutions*

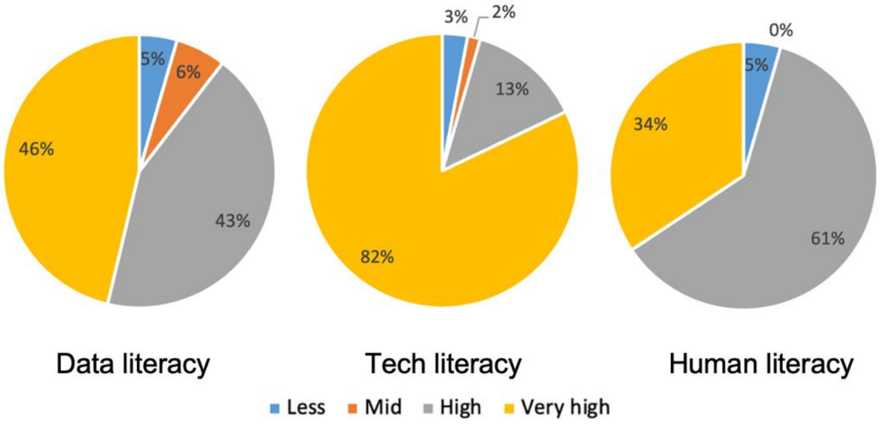

Figure 2. *Percentage of students for each new literacy*

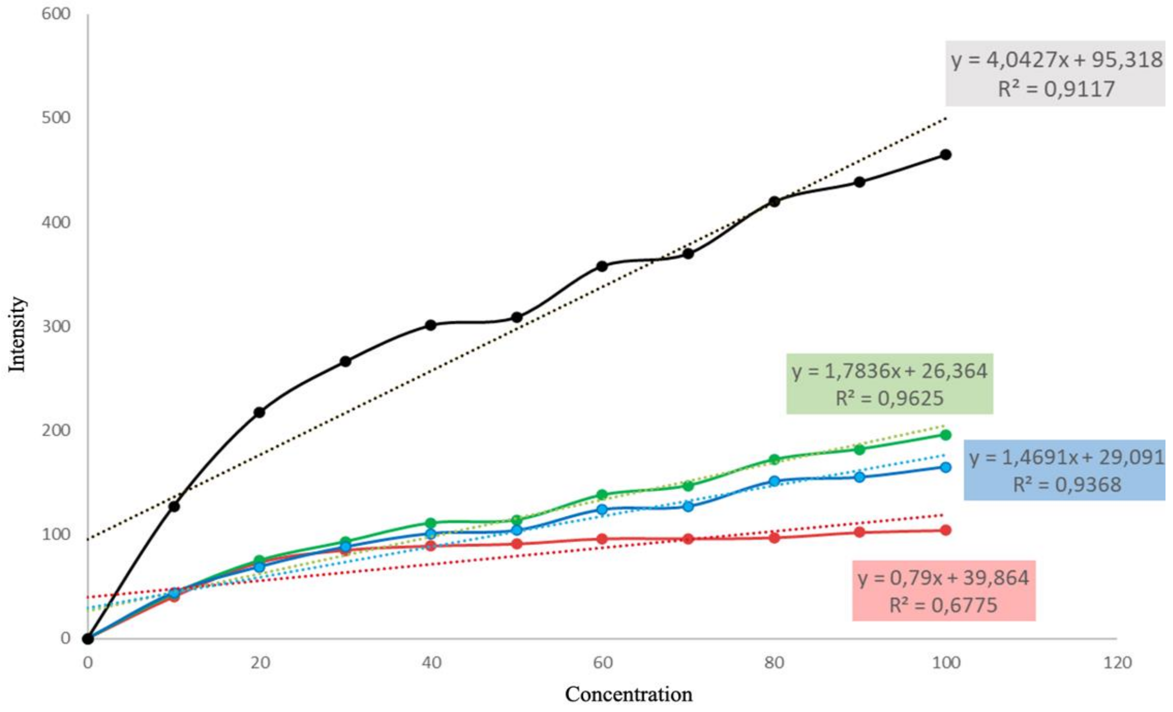

Figure 3. *Example of an experimental result of a calibration curve using digital image data*

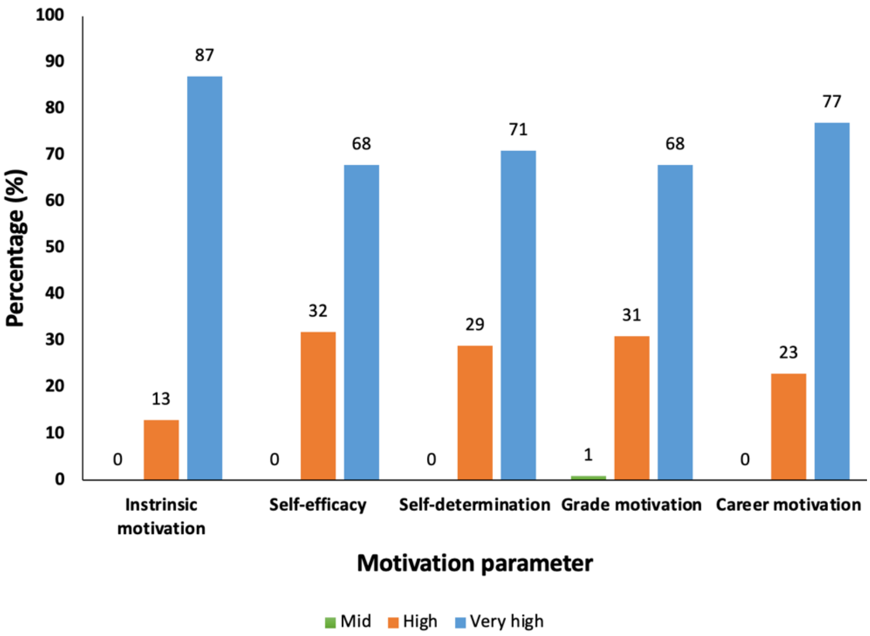

Figure 4. *Distribution of the students according to components of learning motivation*

Table 1. *Recapitulation of the new literacies level in each parameter*

No	parameter	Criteria (%)		
		Less	Mid	High
1	Data literacy			
	a. ability to process pH data of a solution (weak acid, buffer) and to calculate the weak acid equilibrium constant (Ka)	-	39	61
	b. ability to process wavelength and absorbance data, to create calibration curves, and to calculate LoD and LoQ	4	18	78
	c. ability to convert photos into colour image data (RGB), to determine the linearity of RBG data and colour intensity, to create a calibration curve, and to determine the concentration of coloured solutions	6	73	21
2	technological literacy			
	a. ability to use interactive software to obtain experimental data	3	15	82
	b. ability to report experimental results	3	3	94
	c. ability to prepare equipment for project-based experiment	4	-	96
3	human literacy			
	a. ability to conclude verification experiments	4	19	77
	b. ability to compile, design, and report the results of a project-based experiment	4	12	84

Appendix 1. *List of instrumental analysis labwork online*

Experiment	The title of the experiment
1	Determining the dissociation constant of a weak acid using pH-meter software
2	Determining the maximum wavelength complex compound $CoCl_4^{2-}$ using visible spectrophotometer software
3	Determining the maximum wavelength complex compound $Co(H_2O)_6^{2+}$ using visible spectrophotometer software
4	Determining the limit of detection (LoD) and limit of quantitation (LoQ) of the $CoCl_4^{2-}$ complex compound using visible spectrophotometer software
5	Determining the limit of detection (LoD) and limit of quantitation (LoQ) of the complex compound $Co(H_2O)_6^{2+}$ using visible spectrophotometer software
6	Determining the concentration of the coloured solution through digital image measurement

Appendix 2. *Data literacy assessment instruments*

No	Rated work dimension	Achievement level			
		1	2	3	4
Experiment 1					
1	Convert pH value to Ka acetic acid (weak acid solution system)				
2	Conversion of pH to Ka acetic acid (buffer solution system)				
3	Compare measured Ka with reference				
4	Calculate the measurement error				
Experiment 2					
5	Create graph of A versus λ of $CoCl_4^{2-}$				
6	Determine the maximum wavelength of $CoCl_4^{2-}$				
Experiment 3					
7	Create graph of A versus λ of $Co(H_2O)_6^{2+}$				
8	Determine the maximum wavelength of $Co(H_2O)_6^{2+}$				
Experiment 4					
9	Create a $CoCl_4^{2-}$ calibration curve				
10	Determine r^2 of A versus concentration $CoCl_4^{2-}$ curve				
11	Calculate LoD and LoQ from $CoCl_4^{2-}$				
Experiment 5					
12	Create a $Co(H_2O)_6^{2+}$ calibration curve				
13	Determine r^2 of A versus concentration of $Co(H_2O)_6^{2+}$ curve				
14	Calculate LoD and LoQ from $Co(H_2O)_6^{2+}$				
Project work					
15	Determine the relationship of RGB colour image with intensity				
16	Create calibration curve of coloured solutions				
17	Determine r^2 of colour intensity versus concentration of the coloured solution curve				
18	Calculate LoD and LoQ from coloured solutions				

Appendix 3. *Technological literacy assessment instruments*

No	Rated work dimension	Achievement level			
		1	2	3	4
Experiment 1					
1	Use weak acid Macromedia software				
2	Retrieve data correctly (weak acid)				
3	Use buffer solution Macromedia software				
4	Retrieve data correctly (buffer)				
5	Upload report				
Experiment 2-5					
6	Use spectrophotometer Macromedia software				
7	Retrieve wavelength data ($CoCl_4^{2-}$)				
8	Upload report 2				
9	Retrieve wavelength data ($Co(H_2O)_6^{2+}$)				
10	Upload report 3				
11	Collect concentration variation data ($CoCl_4^{2-}$)				
12	Upload report 4				
13	Collect concentration variation data ($Co(H_2O)_6^{2+}$)				
14	Upload report 5				
Project work					
15	Assemble the device				
16	Convert images to RGB data				
17	Select an appropriate colour (RGB) image				
18	Create a calibration curve				
19	Determine sample concentration				

Appendix 4. *Human literacy assessment instruments*

No	Rated work dimension	Achievement level			
		1	2	3	4
Experiment 1					
1	Concluding a better experimental method				
Experiment 2					
2	Inferring the wavelength of the complex compound $CoCl_4^{2-}$				
Experiment 3					
3	Inferring the wavelength of the complex compound $Co(H_2O)_6^{2+}$				
Experiment 4					
4	Selecting the right calibration curve of the complex compound $CoCl_4^{2-}$				
Experiment 5					
5	Selecting the right calibration curve of the complex compound $Co(H_2O)_6^{2+}$				
Project work					
6	Project report format				
7	Report view				
8	Writing				
9	Grammar				
10	Complete information/reference				
11	Project report title				
12	Project goal				
13	Background				
14	Observation data and data classification				
15	Data analysis				

16	Apparatus				
17	Preparing working solution				
18	Creating calibration curve				
19	Determining correlation coefficient value				
20	Determining LoD and LoQ				
21	Creating graphics				
22	Advantages/disadvantages of analytical method				
23	Conclusions in response to research objectives				

Appendix 5. *Science learning motivation questionnaire*

No	Components (scales) and statements (items)	Achievement level				
		1	2	3	4	5
Intrinsic Motivation						
1	The science I learn is relevant to my life					
2	Learning science is interesting					
3	Learning science makes my life more meaningful					
4	I am curious about discoveries in science					
5	I enjoy learning science					
Self-Efficacy						
6	I am confident to do well on science tests					
7	I am confident to do well on science labs and projects					
8	I believe I can master science knowledge and skills					
9	I believe I can earn a grade of “A” in science					
10	I am sure I can understand science					
Self-Determination						
11	I put enough effort into learning science					
12	I use strategies to learn science well					
13	I spend a lot of time learning science					
14	I prepare well for science tests and labs					
15	I study hard to learn science					
Grade Motivation						
16	I like to do better than other students on science tests					
17	Getting a good science grade is important to me					
18	It is important that I get an "A" in science					
19	I think about the grade I will get in science					
20	Scoring high on science tests and labs matters to me					
Career Motivation						
21	Learning science will help me get a good job					
22	Knowing science will give me a career advantage					
23	Understanding science will benefit me in my career					
24	My career will involve science					

No	Components (scales) and statements (items)	Achievement level				
		1	2	3	4	5
25	I will use science problem-solving skills in my career					

Information:

1 : Never
2 : Rarely
3 : Sometimes
4 : Often
5 : Always