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Enhancing Visual Intelligence Through a Triplet Representation-Based Virtual Laboratory on Chemical Equilibrium Shifts

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Abstract

This research examined the validity, practicality, and effectiveness of virtual laboratory based on triplet representation to enhance students' visual intelligence in chemical equilibrium shifts. Using the Research & Development (R&D) method with the Analysis, Design, Development, Implementation, and Evaluation (ADDIE) model, this study involved 31 students from MAN 2 Gresik. The instruments used included validation questionnaire, student response questionnaire, and pre-posttest sheets. The results showed the media achieved very good validity with a mode of four, very practical with practicality test reached 94.08% and effective to enhance visual intelligence in chemical equilibrium shifts with significance value of 0.000 (< 0.05) on Wilcoxon Signed Rank and medium-high category N-Gain. This virtual laboratory based on triplet representation is proven to be valid, practical, and effective in enhancing students' visual intelligence on chemical equilibrium shift. This media can be an innovative solution for digital learning and a cost-effective alternative for schools that lack laboratory facilities.

Keywords: equilibrium shifts, media feasibility, triplet representation, virtual laboratory, visual intelligence

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1. Introduction

Chemistry learning is the foundation for innovation in various fields of science and technology that are often faced with the inherent challenges of the abstract nature of chemistry concepts. Chemical abstraction arises from phenomena that cannot be directly observed, such as interactions between atoms, ions, molecules, and substances in solution. (Gkitzia et al., 2020). Chemical equilibrium, particularly equilibrium shifts, is one of the most abstract topics in chemistry because in this material is studied the dynamic process of chemical equilibrium that cannot be directly observed (Takowa et al., 2025). These characteristics trigger students' difficulties in understanding the concept of chemical equilibrium shifts (Novita et al., 2023).

Students' difficulties in understanding chemistry concepts are often caused by students' inability to connect concepts that can be observed directly and cannot be observed directly (Keiner & Graulich, 2021). Therefore, a chemical representation is needed that can act as a bridge between the concepts of chemistry that can be observed directly and those that cannot be observed directly so that students can build a deep conceptual understanding (Talanquer, 2022).

Chemistry consists of three important components which include macroscopic, submicroscopic and symbolic components (Popova & Jones, 2021). These three components are commonly referred to as chemical representations that must be presented comprehensively in chemistry learning to avoid misunderstanding of chemical concepts (Isaloka & Dwiningsih, 2020). A deep understanding of chemical phenomena, from the macroscopic to the submicroscopic level, requires some visualizations so that learners can meaningfully internalize the concepts (Lin & Wu, 2021).

Visualization for chemical concepts, especially for equilibrium shifts, is important because this material has a high complexity (Garma et al., 2024; Ranggu et al., 2023). Visualization will be able to be processed by students optimally if they have high level of visual intelligence (Khusna et al., 2024). Visual intelligence is defined as the ability to visualize, depict, and manipulate spatial information to solve problems (Maharma, 2021). This visual intelligence consists of four aspects, which are the aspects of imagining, conceptualizing, problem solving and pattern seeking (Rossie et al., 2025). Improved visual intelligence can significantly bridge the gap in understanding abstract chemistry concepts, and ultimately, contribute to improved learner outcomes (Yahya & Lutfi, 2023).

Responding to these problems, a visual learning media is needed that can be used as a learning medium for materials that require a lot of visualization (Silva & Arroio, 2022). In chemistry learning, the use of visual learning media has been shown to be effective in improving visual intelligence and understanding of abstract chemical concepts (Rossie et al., 2025). There are many types of visual media, one of the visual media that can be used is virtual laboratory media (Rosmansyah & Mutiaz, 2024).

Virtual laboratory was chosen because this media can facilitate the practicum-based chemistry learning process. By conducting a virtual practicum, students will be able to more easily understand the relationship of variables that affect the equilibrium shift from observing phenomena that can be observed directly from the simulation process (Takowa et al., 2025). The simulation process is a form of interactive visualization that can help students conduct an in-depth exploration of complex equilibrium shifts from various chemical representations (macroscopic, submicroscopic and symbolic) (Herrington et al., 2022). In the context of 21st century education about technology-based media, virtual laboratory is becoming increasingly relevant and essential. Its main advantages include can be used without restrictions time, reduces chemical waste, safer for students, and can help schools that do not have physical laboratory facilities to be able to conduct direct experiments (Cruz et al., 2025; Sari et al., 2024).

In order to optimize the potential of virtual laboratory as visual learning media, this study integrates a triplet representation: macroscopic (observable phenomena), sub-microscopic (particles and interactions at the molecular level), and symbolic (reaction formulas and equations) (Murni et al., 2022). Fitria & Sebastian (2024) stated that chemistry learning based on triplet representation has been proven to improve students' understanding of concepts. In addition, integrating chemical representations in a learning media can form a mental model (Murni et al., 2022).

These three representations are fundamental in chemistry learning because the concept of chemistry involves both visible and invisible phenomena. By presenting the three representations in an integrated and comprehensive manner in a virtual environment, it is hoped that students can build a more complete and in-depth understanding of chemical concepts, as well as train and improve their visual intelligence systematically (Lestari et al., 2023).

Some literature shows that some previous studies have developed virtual laboratories for chemical materials. For example, the research from Rokhim et al. (2020) focuses on chemical separation, Widarti et al. (2021) on analytical chemistry materials, and Dzikro & Dwiningsih (2021) on elemental chemistry. However, a deep analysis of these previous studies revealed that there are no virtual laboratory media explicitly and comprehensively integrated all aspects of the triplet representation (macroscopic, sub-microscopic, symbolic) on equilibrium shifts focused to enhance students' visual intelligence. The integration of the triplet representation in a form visual learning media like virtual laboratory, is expected to enhance students' visual intelligence, enabling them to understand the abstract concept of chemical equilibrium more easily and deeply. This gap is the foundation and novelty of this research.

Based on the problems and gaps in the literature identified, this study aims to develop and test the feasibility (validity, practicality, and effectiveness) of innovative triplet representation-based virtual laboratory to enhance students' visual intelligence on chemical equilibrium shifts. This media is also expected to be a solution for practicum-based chemistry learning that is more practical, efficient, and adaptive to the dynamics of educational technology developments in this digital era. In addition, by integrating triplet representation in virtual media, this laboratory is designed to be able to guide students in making transitions between representations so that students' understanding of the concept of equilibrium shift sub-material will be more profound.

2. Research Method

This research used the Research & Development (R&D) method with the ADDIE model (Analysis, Design, Development, Implementation, and Evaluation) (Szabo, 2022). The selection of the ADDIE model is based on its characteristics that are systematic and this model is suitable for developing media for education Spatioti et al. (2022).

2.1. Procedure

The research uses the ADDIE development model which consists of several stages as follows.

2.1.1. Analysis

This stage aims to analyze the need to develop learning media in the form of virtual laboratory media based on triplet representation that is tailored to the characteristics of students, needs, learning outcomes and learning objectives.

2.1.2. Design

The design stage aims to prepare a design or storyboard from the virtual laboratory media based on triplet representation to be developed. The preparation of the storyboard consists of several stages, including the stage of determining interactive features in the media, the preparation of an interesting initial media design format and the selection of supporting applications in media creation.

2.1.3. Development

The development stage aims to combine elements in the form of text, images and others into a virtual laboratory media that matches the storyboard. In addition, the preparation of visual intelligence test instruments was also carried out. The virtual laboratory media and visual intelligence test instruments are then validated by three validators who will assess the validity of the virtual laboratory based on aspects of content and construct validity.

2.1.4. Implementation

The implementation stage includes limited product trials in the form of a virtual laboratory that is revised after the validation stage by the validator. This research uses a pre-experimental design, which are one group pretest posttest design, with the research subjects of 31 students in grades XII-6 at MAN 2 Gresik. The participants were selected using a purposive sampling technique based on several criteria, including that students have received equilibrium shifts with conventional learning media and have appropriate equipment to operate the virtual laboratory media.

2.1.5. Evaluation

The evaluation stage is a stage that is carried out to find out whether the development of virtual laboratory media is in accordance with expectations and needs. This evaluation process can be carried out at every stage before so that any shortcomings of the developed media can be identified and can be used as a reference for media improvement.

2.2. Research Instruments

The research instruments used in this research is shown in Table 1.

Table 1. Research Instruments

Aspects	Instruments
Validity	Validation questionnaire sheet
Practicality	Student response questionnaire sheet
Effectiveness	Visual intelligence pretest-posttest sheet

2.2.1. Validation Questionnaire Sheet

Validation questionnaire sheet is used to measure the validity include content validity (aspects of the clarity of the material content) and constructs validity (appearance & layout, use of language and ease of use) of the developed virtual laboratory media. This instrument uses a Likert scale with four scoring categories (1-4). Table 2 shows the validator assessment rubric and Table 3 shows the likert scale that used in this research.

Table 2. Validator Assessment Rubric

Aspect	Indicator
Clarity of the material content	1. Suitability of learning objectives with learning outcomes.
	2. Compatibility of the experiment with the submatter of equilibrium shift.
	3. Compatibility of the chemical representation with the experiments carried out.
	4. Truth of the presented chemical representation.
	5. Compatibility with visual intelligence indicators (imagining, conceptualizing, problem solving and pattern seeking).
Appearance & layout	1. Initial design and appearance.
	2. Color combinations used
	3. Spacing and button layout suitability.
	4. Suitability of spacing and animation layout of lab equipment.
	5. Spacing and layout suitability between texts.
	6. Image layout suitability.
	7. Text readability.
	8. Precision of font type selection.
	9. Font size setting accuracy.
	10. Font color accuracy.
Use of language	1. Compatibility with EYD.
	2. Language is not confusing.
	3. Grammatical conformity of chemical compound formulas.
Ease of use.	1. Easy to download media.
	2. Ease of use of media.
	3. Ease of running virtual experiments.
	4. The button can work properly.
	5. Animations can run well.

Table 3. Likert Scale

Score	Criterion
1	Not Good
2	Enough good
3	Good
4	Very good

(Sugiyono, 2013)

2.2.2. Students Response Questionnaire Sheet

Students response questionnaire is used to measure the level of practicality of virtual laboratory media from students' perspective. This questionnaire uses the Guttman scale that shown in Table 4.

Table 4. Guttman Scale

Statement	Answer	Score
Positive	Yes	1
	No	0
Negative	Yes	0
	No	1

(Sugiyono, 2013)

2.2.3. Visual Intelligence Pretest Posttest Sheet

Visual intelligence pretest posttest sheet is used to measure the level of students' visual intelligence before and after using virtual laboratory based on triplet representation. Pretest and posttest questions were developed based on visual intelligence indicators consisting imagining, conceptualizing, problem solving and pattern seeking. The pretest and posttest questions consist of 10 questions that represent these visual indicators. The number of questions is adjusted to the cognitive load and the duration of the work on the questions by the students. The example of visual intelligence question that used in this research can be shown in Figure 1.

Soal "Pengkonsepan"

Perhatikan persamaan reaksi kesetimbangan berikut:

$CuSO_4$ (s) +5H_2O (l) ⇌ $CuSO_4.5H_2O$ (s)

(putih) (biru)

Pada sistem kesetimbangan tersebut ditambahkan air sehingga terjadi perubahan $CuSO_4$ putih menjadi berwarna biru. Pernyataan yang sesuai mengenai gambar tersebut adalah…

a. Penambahan H_2O menyebabkan kesetimbangan bergeser ke arah kanan yang ditunjukkan semakin banyaknya $CuSO_4$ yang terbentuk.
b. Penambahan H_2O tidak menyebabkan pergeseran kesetimbangan karena tidak ada zat yang bertambah.
c. Penambahan H_2O menyebabkan kesetimbangan bergeser ke arah kanan yang ditunjukkan semakin banyaknnya $CuSO_4.5H_2O$ yang terbentuk.
d. Penambahan H_2O menyebabkan kesetimbangan bergeser ke arah kiri yang ditunjukkan semakin banyaknya $CuSO_4$ yang terbentuk.
e. Penambahan H_2O menyebabkan kesetimbangan bergeser ke arah kiri yang ditunjukkan semakin banyaknya $CuSO_4.5H_2O$ yang terbentuk.

Figure 1. The Example of Visual Intelligence Question

Figure 1 presents an example of a visual intelligence test item employed in this research. The item evaluates students' ability to interpret visual information related to chemical equilibrium and to connect macroscopic changes with symbolic representations, in line with the triplet representation framework.

2.3. Data Analysis Techniques

The data obtained was then analyzed using the following data analysis techniques.

2.3.1. Validity Analysis

The validity data of the virtual laboratory media was analyzed using the mode value. Virtual laboratory media is declared valid if this media get a minimum mode score of three so that it can be continued at the limited trial stage. The score given by the validator is based on the following likert scale that showed in Table 3.

The assessment from the validators is then calculated as the percentage of agreement (PA) which states the percentage level of compatibility of the validators. Here's the formula used.

$$(PA) = \left(1 - \frac{A-B}{A+B}\right) x\ 100\% \quad (1)$$

Remarks:
A = greater validator score
B = smaller validator score

The percentage of agreement with a value > 75% indicates a good category (Egista et al., 2022).

2.3.2. Practicality Analysis

Media practicality data from the student response questionnaire sheet was then calculated using the following equation.

$$P = \frac{\Sigma X}{N}\ x\ 100\% \quad (2)$$

Remarks:
P = Percentage of Practicality (%)
ΣX = Number of scores obtained
N = Maximum score

The virtual laboratory media is declared practical if it obtains a percentage of practicality at least 61%. The media practicality criteria can shown in Table 5.

Table 5. Media Practicality Criteria

Score (%)	Criterion
81 - 100	Very Practical
61 – 80	Practical
41 – 60	Quite Practical
21 – 40	Less Practical
0 - 20	Impractical

(Riduwan, 2016)

2.3.3. Effectiveness Analysis

The data on the students' visual intelligence pretest and posttest scores were then analyzed using IBM SPSS Statistic 23.0 to conduct the Saphiro Wilk normality test (Sudirman 2023). If the data is distributed normally, it will be followed by the Paired Sample *t*-test. And if it is not distributed normally, it is followed by the Wilcoxon Signed Rank test.

Decision-making in the paired sample *t*-test or Wilcoxon Signed Rank uses the following hypothesis:

H_0 : There was no significant difference between *pretest* and *posttest* after the use of virtual laboratory based on triplet representation media.

H_a : There is a significant difference between *pretest* and *posttest* after the use of virtual laboratory based on triplet representation media.

The virtual laboratory media is declared effective if it gets . *Sig (p-value)* ≤ 0.05 which states H_0 is rejected and H_a is accepted.

In addition, N-gain score were also carried out to determine the increase of students' visual intelligence after the use of this virtual laboratory media. N-gain *(g)* can be calculated by the following formula:

$$g = \frac{post\ score\ -\ pre\ score}{max\ score - pre\ \ score} \qquad (3)$$

The media is declared effective if it gets N-gain score of ≥ 0.30 in the medium-high category. The category of increased visual intelligence can be known based on the Table 6 of N-gain criteria as follows.

Table 6. N-Gain Score Criteria

N-Gain (g)	Criteria
g < 0.3	Low
0.3 ≤ g < 0.7	Medium
0.7 < g	High

(Sirianansopa, 2024)

In addition, r (effect size) calculations were also carried out. This effect size value will show how does a treatment affect a variable (Zieliński & Gawda, 2024). Effect size can be calculated with the following equation.

$$r = \frac{Z}{\sqrt{N}} \qquad (4)$$

The effect of using virtual laboratory media based on triplet representation in chemistry learning, especially to improve visual intelligence. Table 7 shows the interpretation of the effect size value, virtual laboratory is considered to have an influence on improving visual intelligence if the effect size value is at least 0.3.

Table 7. Effect Size Criteria

Effect Size	r
Small	0.10
Medium	0.30
Large	0.50

(Zieliński & Gawda, 2024)

3. Result and Discussion

3.1. Analysis

The analysis stage consists of student analysis, needs analysis and analysis of learning outcomes and learning objectives. At the beginning of the analysis, an analysis was carried out on the characteristics of students. Based on the students analysis, it is known that students have difficulty in understanding the concept of chemical equilibrium shift. In line with Keiner & Graulich (2021), one of the reasons underlying the difficulties of the students is the inability of the students to connect the three levels of chemical representation. This chemical representation is synonymous with visualization. In understanding the various forms of visualization, students need high visual intelligence (Khusna et al., 2024). So that the difficulty of students in learning chemistry is also related to the low visual intelligence of students. Therefore, visual media is needed that can stimulate the visual intelligence that students actually have (Rossie et al., 2025).

One of the visual media that can be used is virtual laboratory (Rosmansyah & Mutiaz, 2024). In addition, according to (Alhashem & Alfailakawi, 2023), virtual laboratory media can be chosen because this media can support ideal chemistry learning, which is practicum-based. In the learning outcomes of chemistry in "*Kurikulum Merdeka*", it is also stated that students are expected to be able to develop a deep understanding of concepts regarding chemical equilibrium shifts and their application through several process skills, including the skills of observing, predicting, investigating, analyzing, and reflecting.

Using virtual laboratory media, students can be more flexible in conducting practicums. According to the results of interviews with chemistry teachers, the existence of virtual laboratory media is expected to be used as an alternative media for schools that have limited facilities, such as the availability of school physical laboratories. Considering several things that have been observed in the field, to enhance students' visual intelligence can be done by using virtual laboratory based on triplet representation.

3.2. Design

The design stage consists of the preparation of storyboards and test instruments. Storyboards are prepared based on several stages, including the stage of determining interactive features in the media, the preparation of an interesting initial design format of the media and the selection of supporting applications in media creation. Some of the applications used in the preparation of the media include the *Canva* and *Adobe Animate 2021*.

The preparation of visual intelligence test instruments is based on the four indicators of visual intelligence, including imagining, conceptualizing, problem solving and pattern seeking. The questions prepared consisted of 10 multiple-choice questions.

3.3. Development

At the development stage, the merging of media elements using *Adobe Animate 2021* resulted in draft one which is shown in the following Figure 2. Draft one of the media is in the form of triplet representation-based virtual laboratory which consists of several menu sections including a menu of user guides, learning outcomes and learning objectives, virtual laboratory, visual intelligence questions exercises and developer profiles.

This virtual laboratory media is also equipped with background music that can be activated and deactivated through the sound button in the upper right corner. On the visual laboratory menu, students can also repeat the experiment by clicking the replay button. After conducting session in the virtual laboratory section, students can do visual intelligence exercises in the practice question section. The virtual laboratory media display can be seen in Figure 2.

Figure 2. Virtual Laboratory Media Display

Draft one virtual laboratory media based on triplet representation that has been developed was then validated by several expert validators. The validation process of the virtual laboratory media based on triplet representation involves three validators including two chemistry lecturers from FMIPA Unesa and one chemistry teacher. The validation carried out consists of content validity (clarity of material content) and construct validity (appearance & layout, use of language and ease of use). The results of the media validation can be seen in Table 8.

Table 8. Media Validation Results

Aspects	V_1	V_2	V_3	Mo
Clarity of material content	4	3	4	4
Appearance and layout	4	3	4	4
Language Use	4	3	4	4
Ease of Use	3	3	4	3

Based on the results of the validation that has been carried out, it can be seen that the learning media developed obtained an assessment mode of four on the content and construct validity.

Furthermore, based on the results of the percentage agreement (PA) calculation, it shows a value of 88%. This value indicates good results because it is above 75%. With this value, it shows that there is a good compatibility between validators so that it can strengthen the validation results of the virtual laboratory media based on the triplet representation developed. So that it can be stated that this virtual laboratory media has very good criteria and is suitable for use on limited trials after revision based on input and suggestions from validators.

3.4. Implementation

The form of virtual laboratory based on triplet representation which has been validated and revised to produce draft two which was then tested on a limited trial at MAN 2 Gresik. This limited trial was attended by 31 students in grades XII-6.

3.4.1 Practicality Test

Students who have used virtual laboratory media in a limited trial will fill out a student response questionnaire to determine the practicality of the media. Some of the aspects that were assessed using the response questionnaire consisted of aspects attractiveness of the media, ease of use and clarity of the material content in the media. Table 9 shows the recapitulation of the results of student response questionnaire.

Table 9. Recapitulation of Student Response Questionnaire Results

Aspects	(%)	Category
Media Attractiveness	92.93	Very Practical
Ease of Use	96.77	Very Practical
Clarity of material content	93.54	Very Practical
Average percentage	**94.08**	**Very Practical**

The results of the student response questionnaire in Table 9 obtained the very practical category with a practicality percentage of 94.08%. The findings indicates that as long as students use laboratory virtual laboratory media, students do not experience difficulties and confusion so that chemistry learning can run effectively. This is in line with Riduwan (2016) which states that the media is said to be practical if the percentage of practicality is more than 61%.

3.4.2 Effectiveness Test

The media effectiveness test was carried out during the limited trial through filling out visual intelligence pretest and posttest sheets in the form of multiple choice by students. From the results of the visual intelligence pretest and posttest, an N-gain score *(g)* was calculated so that it can be known that the increase in students' visual intelligence after the use of virtual laboratory media can be known. Figure 3 showed the result of visual intelligence pretest-posttest.

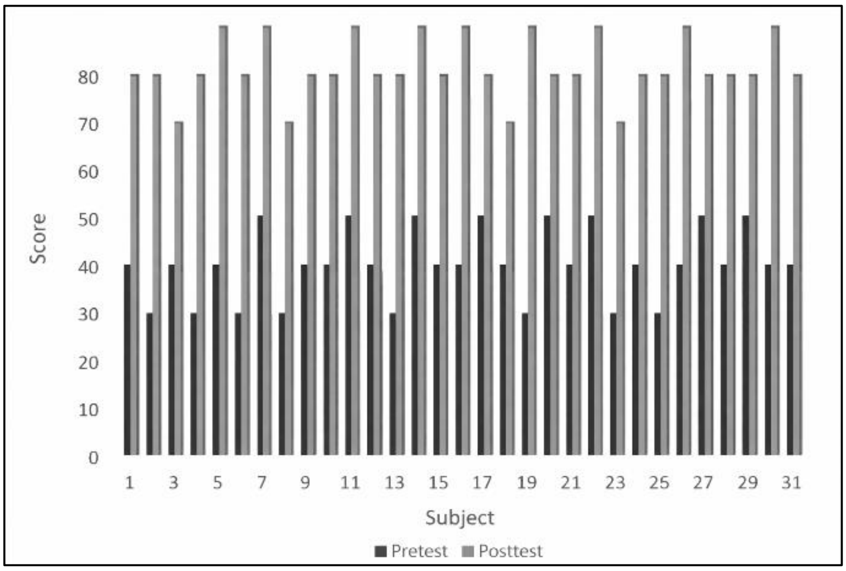

Figure 3. Visual Inteligence Pretest Posttest Score

Based on data from *the results of the pretest* and *posttest* of visual intelligence, as many as 31 students who have used virtual laboratory media based on triplet representation in chemistry learning obtained n-gain score in the score range of 0.5 – 0.86. According to Sirianansopa (2024), n-gain scores ≥ 0.3 are included in the medium to high category. According to Figure 4, 55% of students are in the medium improvement category and 45% are in the high improvement category. These results indicate a significant improvement in students' visual intelligence.

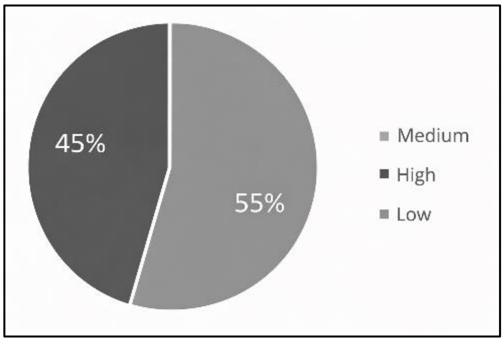

Figure 4. N-Gain Score

Further analysis showed that the increase in visual intelligence based on n-gain score when reviewed by four visual intelligence indicators showed different score. The n-gain score for the conceptualizing indicator is 0.7, the imagining indicator is 0.53, the problem-solving indicator is 0.47 and the pattern seeking indicator is 0.73. The differences in N-gain scores across indicators suggest varying levels of improvement level of visual intelligence in each indicator. For imagining and problem solving indicators, which are lower than the other two indicators, it shows that adjustments are still needed to the virtual laboratory media to be able to enhance students' visual intelligence which will later be needed to solve chemical problems.

The significance of changes in *visual intelligence pretest* and *posttest scores* was then analyzed using SPSS. First, a *Saphiro Wilk normality test* was carried out as a prerequisite test. Table 10 showed the results of Saphiro Wilk's normality test.

Table 10. Saphiro Wilk's Normality Test

	Shapiro-Wilk		
	Statistic	**df**	**Sig.**
Pretest	.812	31	.000
Posttest	.781	31	.000

Based on the results of the normality test of Saphiro Wilk (Table 10) obtained .*Sig* is 0.000 for *pretest* and *posttest*. According to Sudirman et al. (2023), if the .*Sig* in the normality test > 0.05, then the data is declared to be distributed normally. So that the *pretest* and *posttest* data were declared abnormal and continued to non-parametric analysis using *the Wilcoxon Signed Rank*. The Wilcoxon Signed Rank test is conducted to find out the significant difference between *the pretest* and *posttest* scores of students' visual intelligence.

Based on *the* result of *Wilcoxon Signed Rank* test, it is obtained. Z=-4.946 and Asymp. *Sig* (2-tailed) of 0.000 (<0.05) indicates that H_0 is rejected so that Ha is accepted. This result states that there is a significant difference between the pretest and posttest scores. Higher posttest scores when compared to pretest scores indicate an increase in visual intelligence. Furthermore, the value of effect size (r) was calculated and showing a value of 0.88. These values show that the use of laboratory virtual media based on triplet representation in chemistry learning also indicate a large upside effect to enhance visual intelligence.

Looking at the significant differences in pretest and posttest scores from *Wilcoxon Signed Rank*, N-Gain scores of students who fall into the medium-high categories and the effect size indicating that this triplet representation-based virtual laboratory media has the potential to be used as a learning media to be able to improve students' visual intelligence which is reviewed by four indicators (conceptualizing, imagining, problem solving and pattern seeking. By using this virtual laboratory media, students will be able to learn chemistry more completely, pay attention to macroscopic symptoms through color changes, see the equilibrium process at the particulate level through particle animation and relate it to symbols, formulas and equations of chemical equilibrium reactions. In line with Hu-Au (2024), doing practicum virtually can cause the process to understand chemical concepts from the macroscopic and submicroscopic levels to be bridged well.

The mechanism of receiving information in the learning process with virtual laboratory media is in line with the theory of dual coding. According to Wooten & Cuevas (2024), the dual coding theory emphasizes that the reception of information can be processed through two paths, which are verbal and non-verbal (visual). As for the non-verbal pathway, this can be in the form of providing visualization. If students receive information presented in verbal and non-verbal form at the same time, it will affect their understanding of the concept (Wu et al., 2025).

In chemistry learning, visualization is synonymous with depicting various chemical phenomena from the macroscopic, submicroscopic and symbolic levels. (Popova & Jones, 2021). However, students who are unable to connect the three will find it difficult to understand chemical concepts. In line with research by Ripsam & Nerdel (2024) which states that a comprehensive understanding of chemical concepts is greatly influenced by the ability of students to translate the three levels of chemical representation both at the macroscopic, submicroscopic and symbolic levels. And this chemical representation is identical to visualization (Phajan et al., 2025).

The ability to translate all the three levels of chemical representation is closely related to high visual intelligence. According to Khusna et al. (2024), with high visual intelligence, various forms of information in the form of visualizations presented will be easier for students to understand. In addition, the choice of visual media in the form of a virtual laboratory based on triplet representation as a visual intelligence stimulus is the right choice. According to the research by Rokhim et al. (2020) and Dzikro & Dwiningsih (2021) stating that the use of virtual laboratory media has proven to be feasible and can provide a meaningful learning experience and improve student learning outcomes. However, the study did not consider the visual intelligence factor of each student which has an influence on the process of understanding chemical concepts that are identical to visualization.

The integration of triplet representations in virtual laboratory media is supported by the results of the research by Widarti et al. (2021) which states that virtual laboratory with the integration of three levels of chemical representation can be bridge for students in understanding abstract chemical concepts. This strengthens the results of this research which states that virtual laboratory media based on triplet representation has been proven effective in enhancing visual intelligence, so that abstract and concrete chemical concepts can be bridged well and have an impact on the complete understanding of chemical concepts received by students.

The success of the implementation or trial of this virtual laboratory based on triplet representation media can be influenced by several factors. One of the important factors underlying it is the internet connection factor. The virtual laboratory media used can be run offline. However, students are required to download this virtual laboratory media file on their computer or laptop. According to Deriba et al. (2024), the internet connection factor will be able to affect the success of the implementation of virtual laboratory media because if teachers or students do not have a good internet connection, then practicum learning with this virtual laboratory will be hampered. In addition, virtual laboratory media can only be run on laptops or computers, so it limits the accessibility of students who do not have these devices.

3.5. Evaluation

The evaluation stage was carried out in several previous stages to be able to improve the developed virtual laboratory media. One of the evaluation processes was obtained from suggestions and input from validators. At this evaluation stage, suggestions for improvement for further research were also prepared, including that at the implementation stage, a larger section can be used with a controlled experimental design (Pretest-Posttest Group Design) so that the effects caused after learning can really be known from the implementation of this virtual laboratory media. In addition, it is hoped that interview or observation methods can be used so that students' behavior related to the four indicators of visual intelligence will be observed.

Long-term retention/delayed retention tests can also be used to find out if these methods and media can lead to more meaningful, deeper learning and stored in long-term memory (Timmer et al., 2020).

4. Conclusion

Based on the results of this research, it can be concluded that the development research of triplet representation based-virtual laboratory has met the research objective, which is to produce a feasible triplet representation based-virtual laboratory by meeting valid, practical and effective criteria to improve students' visual intelligence. This is evidenced by the validity value of the media is four with the very good category, the percentage of practicality is 94.08% with the very practical category, the N-gain score of the visual intelligence improvement category is medium-high, and the value of *.Sig* for *Wilcoxon Signed Rank* is 0.000 (<0.05) which states that this triplet representation-based virtual laboratory has a significant effect on improving students' visual intelligence.

This virtual laboratory media has the potential to be used as an alternative to technology-based chemistry practicum learning that is worthy of further development by integrating Virtual/Augmented Reality that can be tested on a larger scale.

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