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# ORGANISING MULTIPLE-DIMENSIONALISING COMPREHENSION ACTIVITIES TO DEVELOP CHEMISTRY CRITICAL THINKING ABILITIES FOR HIGH SCHOOL STUDENTS

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**ABSTRACT**

*Multiple-dimensionalising conprehension is a process consisting of a series of exercises happening continuously in a sepcific period of time with the starting point being the process of multiple-dimensionalising comphrehension, following by the process of self-comprehension, and ending with the process of self-adjusting comprehesion. The product of this series of exercise is the result of the positive reviews, analyis, evaluation, adjusting comprehension in order to achieved pre-set learning objectives. Through this, it reflects the mental flexibility of the the learner; further more, it helps student achieved the accuracy, the efficiency in the process of gaining knowledge and adjusting comprehension.*

***Keywords:*** ability, critical thinking, multiple-dimensionalising comprehension, teaching chemistry.

**TÓM TẮT**

***Tổ chức hoạt động đa phương hóa nhận thức theo hướng phát triển năng lực tư duy phê phán Hóa học cho học sinh trường trung học phổ thông***

*Đa phương hóa nhận thức là một quá trình gồm dãy các hành động liên tiếp xảy ra trong một khoảng thời gian xác định với điểm xuất phát là quá trình nhận thức đa chiều, tiếp theo đó là quá trình nhận thức bản thân, kết thúc là quá trình tự thay đổi nhận thức. Sản phẩm của hoạt động này là kết quả của các hoạt động xem xét tích cực, phân tích, đánh giá, điều chỉnh nhận thức nhằm hướng tới các mục tiêu học tập đã đề ra. Qua đó, nó phản ánh tính linh hoạt, mềm dẻo trong tư duy của người học, ngoài ra nó còn giúp HS đạt được sự chính xác, tính hiệu quả trong hoạt động lĩnh hội kiến thức và điều khiển quá trình nhận thức.*

***Từ khóa:*** năng lực, tư duy phê phán, đa phương hóa nhận thức, dạy học Hóa học.

## 1. Introduction

The rapid advancement of technology in the XXI century has created countless high-quality material and intellectual products for the modern society. This requires each nation to constantly innovating, adapting to the changes to daily life. To resolve these challenges, the Education and Training industry must be the pioneer and take on the role of improving

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intellectuals, discovering and nurturing talents to improve their quality. In other words, education is not just for the products of comprehension, but it also needs to focus more on the renovation of thoughts to create talents that has both the qualities and abilities of a XXI century person. This conclusion had been researched and confirmed in a number of developed nations like: United States, Canada, the United Kingdom, Russia... (Barell, J., 1995, p.81-82). To achieve such success, they had applied the development theory of critical thinking in education.

In the midst of globalisation, the phrase "development of critical thinking" is one of the most vital mission of a nation in the process of industrialisation and modernisation following the directive of Socialism. Its importance is shown in the Resolution of The 8th Central Conference Part XI of the Central Executive Committee of the Party about the comprehensive renovation of the basis of education and training (Resolution number 29-NQ/TW), which also points out the development of critical thinking will be a strategic goal of the development of education in the period of 2011-2020 (issued alongside Decision 711/QD-TT on the 13/06/2012 of the Governmental Prime Minister) "*Focus on the development of intellect, physique, building the citizen's qualities, abilities, discovering and nurturing talents, career guidance for students…"*

Chemistry is an applied science, meaning each theory, law, concept, personal observation... begins from phenomenon, experiments, realistic production process. To study and research chemistry, the leaner must have the skills to: observe, analyse, evaluate, judge, utilise their chemistry knowledge appropriately to produce accurate and scientific results. Because of this, developing the ability to think critically is one of the possible solution that could help student cultivate the above-mentioned skills and achieve insights that are accurate, extensive, and comprehensive about scientific subjects.

## 2. Research content

### *2.1. Viewpoints of critical thinking*

According to the well-known American psychologist Baron J.S. and Sternberg R.J. (2000) "Critical thinking is thinking with consideration, deliberation to decide rationally when understanding and deciding on a subject" *(*p.15). Similar to the above, the French psychologist Ennis, R. (2007) states *"Critical thinking is thinking in a way that is rational focusing on the subject matter in order to create belief and action"* (p.10).

From a narrower and more detailed point of view, Phan, T.L. (2008) states: "Critical thinking is thinking with consideration, deliberation, evaluation and association between all related aspect of all the information sources with a subjective and positive attitude based on determined standards to find the most appropriate information to solve the listed problems" (p.56). Agreeing with this statement, the author Le, H.Y. (2008) also listed her own definition about critical thinking like so:

Critical thinking is a thinking with consideration, deliberation to come to a rational decision when understanding or proceeding with a subject matter. To improve critical thinking, one must focus on skills that can make clear, that constitute an argument, to explain the correctness and authenticity of information (observation, interaction), put forward questions to deepen understanding, to be able to counter your argument, the skills to reason, argue, infer. (p.12).

From the aggregation, analysis, and evaluation of the above-mentioned statements, the author finds that: "Critical thinking is the action of continuously performing intellectual activities such as: inferring, comparing, analysing to evaluate, correct, and solve the remaining existences hidden in the subject matter. From another point of view, critical thinking is considered an activity with a high degree of imagination, expressing through the proposal and selection of new and optimal solutions to deal with newly formed subject matter with a more complete, multiple-dimensionalising and comprehensive scientific approach.

### *2.2. Expressions of critical thinking*

Robert Ennis (2007) is the pioneer with the suggestions that the expressions of critical thinking ability in people is a combination of the following: "observation skills, imagination skills, associations skills, scientific scepticism skills, flexibility skills, multiple-dimensionalising skills"(p.115). However, according to Donald J. Treffinger (2008), people with the ability to think critically always have the following common expressions:

> "they always propose intelligent decisions, are conscious of thinking things through, to find innovative, unique, and optimal solution for all obstacles that society requires, become people who are positive, progressive, civilised, and sober to find solutions that are unique, to work, for the existence and development of human society"(p.34).

In the resources written by the author Tran T.T.H (2011), she also mentioned the expressions of critical thinking of high school student through the teaching of inorganic chemistry are:

> "know how to find the problem, find the solution to said problem; plan and perform the plan to get the results wanted; propose a solution quickly and effectively; propose a plan in their own unique way of thinking; know how to renovate old methods; know how to predict the result, the test and the conclusion; know how to self-evaluate and evaluate the different results, products and propose a plan for completion" (p.88-89).

Based on this, the resources written by the author Pham T.B.D (2015) also mentioned the expressions of critical thinking in the teaching of organic chemistry in high school as follow:

> "find the problem in the pre-set situation; propose different experiment to confirm theories, answer the research question; proposed different solutions to the problem; renovate old method, propose new method in the learning activities; debate, counter and protect their opinion or their group's opinion; evaluate and self-evaluate the results of the activities or the results of the research of the group or of themselves" (p.56).

From the results obtained from the process of aggregating, analysing, we find that the following expressions are the first expressions of critical thinking abilities in chemistry:

First is "**find the problem**", this is the ability to discover, analyse key points, core points or hidden meaning in each learning objectives.

Second is "**scientific scepticism**", this is the ability to ask themselves questions in order to correctly identify the process of solving the problem/leaning objectives.

Third is "**mental flexibility**", this is the ability to fluently combine different mental exercise (compare, analyse, evaluate, aggregate) and the ability to infer (generalise, associate, imagine, abstract) to provide accurate and scientific conclusion. Furthermore, the mental flexibility is also shown in the ability to self-adjust or self-change the components of the plan when needed.

Fourth is "**evaluate and self-evaluate**", this is the ability to find restrictions and imperfections in knowledge of themselves and others, from which they can find the appropriate solution to correct them.

Above we have mentioned the elements required and important in the development of critical thinking for students. However, they can be adjust according to ability, comprehension capability of the learner as well as the achievement in knowledge, ability, attitude of the learning objective.

### *2.3. The structure of critical thinking in chemistry*

Through the research and analysis of critical thinking ability, the goal of the curriculum and textbooks of high school Chemistry, the author believes that the development of critical thinking in chemistry can be understood as creating an environment and condition appropriate for the student to have a scientific scepticism, multiple-dimensionalising thinking, independent and imaginative thinking in order to create new and improved products. Based on this, along with a critical specialist the author proposes the structure of critical thinking in chemistry as follow:

***The ability to analyse chemistry problem*** is the ability to discover the nature of the relationship between each subject in a chemistry problem.

***The ability to evaluate chemistry problem*** is the ability to utilise scientific arguments to protect their own opinion and thinking, from which they can arrive at a conclusion with a scientific value about the subject matter at hand.

***The ability to aggregate chemistry problem*** is the ability to use their imagination to utilise the correcting solution to the remaining existences hidden in the chemistry problem.

### *2.4. Expressions of critical thinking in chemistry*

With the goal of insuring the accuracy in the evaluation of critical thinking in chemistry, the author has combined the specialist method and the analysis method to determine the expressions of each ability composing up critical thinking ability in chemistry.

***Table 1.*** *The expressions of critical thinking abillity in high school students*

| Component ability of critical thiking | Expressions of critical thinking ability in chemistry |
|---|---|
| The ability to analyse chemistry problem | 1. Recognise the nature of or the law that is operating in this chemistry problem.<br>2. Propose questions relating to the chemistry problem at hand.<br>3. Explain the chemistry problem. |
| The ability too evaluate chemistry problem | 4. Identify the limitations that need to be corrected.<br>5. Protect your own opinions and thoughts.<br>6. Come to a conclusion about the chemistry problem. |
| The ability to aggregate chemistry problem | 7. Propose different scientific theories.<br>8. Build a plan to carry out these theories.<br>9. Carry out the plans independently and imaginatively.<br>10. Self-modify the plans when unsuccessful in solving the chemistry problem. |

### *2.5. Organising multiple-dimensionalising comprehension activities to develop abilities*

The unique point of teaching to develop abilities is that the teaching must be based on the characteristic, needs of the learner, in which the teacher has the role of organiser, controller, helper, and encourager to help the learner discover, perceive knowledge, form and develop abilities of their own accord according to a set teaching goal. To satisfy the above-mentioned condition, the organisation of multiple-dimensionalising comprehension activities is one of the solutions that has a high chance of working and efficiency in the current teaching environment. This is a teaching method of self-perceiving - self-evaluating – self-adjusting comprehension meaning the learner had to have the ability to research and extract information from different resources to solve questions, missions, learning situations that had been proposed. After this, the leaner must self-evaluate the advantages and disadvantages in the thinking process in order to extract the learning experience, propose plans, methods of learning for the next studying periods. The focus of this method is that the student must form their own knowledge from many sources of information under the supervision and instruction of the teacher.

*2.5.1. The definition of multiple-dimensionalising comprehension activities*

Multiple-dimensionalising comprehension is a process of a series of activities continuous happening in a specific period of time with the beginning being the multiple-dimensional comprehension (consideration, deliberation, thinking from all the different viewpoints and aspects about the problem that needs to be solve), continuing onto the self-comprehension (self-analysis, self-evaluating about the solution to the problem), ending

with the process of self-adjusting comprehension (adjusting thinking to come up with strategic solutions).

Multiple-dimensionalising comprehension activities shows the ability to think in multiple dimensions (consideration, evaluating the problem from different viewpoints and aspects) and the ability to self-adjust and change of student to be compatible with the mission/goal of learning that had been set. These activities show the flexibility, the efficiency in the activity of perceiving knowledge and modifying the process of comprehension.

*2.5.2. The purpose of organising multiple-dimensionalising comprehension activities*

Based on the research on the structure, expressions, and evaluation criteria critical thinking ability of students, the author had divided the multiple-dimensionalising comprehension activities into 3 stages:

**Stage 1: Multiple-dimensional comprehension.** This stage assesses the ability to utilise their knowledge, ability, experience that has been gained in the process of self-comprehension. This stage includes activities like: knowing what their knowledge contains; identify the learning goals; considering the various resources and information sources; multiple-dimensional thinking (thinking from different viewpoints and aspects) about the set missions; find a way to evaluate the process of completion; comprehending the advantages and disadvantages in the process of learning.

In this stage, the teacher will ask the student to think about the chemistry problem in multiple dimensions and direction with different viewpoints and from different aspects. Through which the teach may be able to evaluate the analysis capability of the student through self-comprehension activities such as: determining the relation, the law which the subjects are operating under, the component of the operation; utilising their knowledge and experience to simplify the learning goals; self-analyse, self-propose, self-perform the process to completing the leaning objectives with different ways.

**Stage 2: Self-comprehension.** This stage measures the ability to follow, evaluate the advantages and disadvantages in thinking of the self in specific situations and learning objectives. Because of this, each student will self-evaluate, self-review about the efficiency of the thinking process, after which they will devise and decide on a strategic learning method for each learning period. Through the established criteria the student can self-reflect on their own process of studying and the strategies that were used. To achieve high efficiency in this period the student must answer for themselves the following questions: Before, have I performed this learning objective? Why do I find this objective easy or hard? What have I learned? How can I perform it? Should I perform it as I did before?...

In this stage, the evaluation ability of student is measured through activities such as: self-review, analyse the advantages and disadvantages in their own thinking (many things can be done, cannot be done, reason why they cannot be done); propose specific and

scientific proof to explain the reason why the learning objective was not completed (difficulties in researching for related information, intellectual support tools such as: mathematic formulae, related laws of physic, modern chemistry theories); correct shortcomings in thinking (self-comprehending the knowledge required, utilising them to complete learning objectives, reflect on the process of re-completing the objectives).

**Stage 3: Self-adjusting comprehension.** This stage measures the student ability to positivise thinking, self-adjusting one own comprehension. This is shown through the action of pondering about the process of thinking and their own knowledge base from past periods. From this, the student will change in the direction of building new learning plans and strategies in order to satisfy the requirement of an in-depth chemistry program. To perform well at the objectives in this stage, the student must answer the following questions: What is the nature of the learning objectives (lesson, chapter, content of each section)? What kind of information and assisting knowledge do I need to use to correct the imperfection of thoughts? How much time will I need? Do I understand the objectives clearly? Have I achieved the objectives? What have I done and not done? What can be done differently in following attempts? In this period, the ability to aggregate chemistry topics can be evaluate through these activities: propose the information needed to be acquire in the times to follow (goals, assisting knowledge that needs to be supplement, improving practical chemistry skills…), self-initiate new learning objectives (building a plan to complete learning objectives; collect, aggregate objectives from multiple sources); split up the performance of those learning objectives (aggregate topics that had been self-comprehended; evaluate, aggregate the different solutions; compare the means of performance of learning objectives with groupmates/classmates); extract the experience for ones self from the failure/limitations of others (reviews each other on the different solutions; propose, improve the new solution; extract the experience from different reviews and evaluations).

*2.5.3. Performing the multiple-dimensionalising thinking activities*

Multiple-dimensionalising thinking activities can be perform through 3 stages including 9 steps, each stage will evaluate the critical thinking ability in chemistry the student had achieved. The specific are as follow:

**Stage 1. Multiple-dimensional comprehension** is the period the teacher instructs the students on how to develop the ability to think for themselves, to self-evaluate and self-track the thinking process when completing a learning objective. This stage consists of 4 steps as follow:

**Step 1.** The teacher will demonstrate and explain for the student the way to track, adjust, and evaluate their thinking process. Before asking the students to solve a problem, the teacher could play a companion role to assist the students with a similar problem. This can be done by following some of these steps:

- The teacher will accompany the student in researching the basic knowledge or assisting knowledge required to complete the objectives.
- The teacher will engage with the student to create a plan to solve the problem.
- The teacher will share with the student the methods to find and connect important theories or find the connecting point, core point to solve the problem.
- The teacher will instruct the student on how to use deductive methods, develop theories, adjusting direction when encountering obstacles or dead ends.

**Step 2.** The teacher will ask the student to think, consider a chemistry problem from multiple aspects and viewpoints. In cases where the content's difficulty is higher than the comprehension ability of the learner, the teacher may use leading questions to test, gauge the knowledge base and experience of the student, from which they can guide the student onto the direction of the solution. These leading questions could be: This problem would require the utilisation of which theories, which laws? Which content does this problem relate to? Which characteristic (qualitative, quantitative) of the participants has the problem given us in the theory? What is the relationship between the theory and participants?

**Step 3.** The teacher will use question to ask the students to identify the goal, learning objectives. Example: Can you name the steps required to solve this problem?

**Step 4.** The teacher will use questions requiring the student to follow, adjust the thinking process, learning process: Of the steps required to solve this problem, which was the hardest step? Why? When performing this step, what was the difficulties? Is there a way to solve these difficulties? What was the reason why you could not find the answer to this problem? Why does these theories not apply for this problem? Could you have modified, changed, supplemented, improved… in any way to apply it in this problem?

**Stage 2. Self-comprehension** is the period when the student self-analyses, self-evaluate the level of achievement in thoughts, from which the student may propose new thinking methods or improve upon the old methods to correct imperfection in their own thinking. This stage consists of 2 steps:

**Step 5.** The teacher will use questions that requires the student reflect upon the thinking process, the learning process and the results comparing to the goals and plans that had been proposed: During the teaching period, what have you managed to do? What have you not done? What was the cause of your mistakes? What was the reason for your mistakes? What knowledge do you require to correct these mistakes?

**Step 6.** The teacher will organise discussions (in pairs or in groups) for students to present and explain their solutions. Through this, other students will be able to find their own shortcomings as well as gaining precious experience in the process of correcting the remaining hidden limitations.

**Stage 3. Self-adjusting thinking** is the stage where the student will change their own method, their own form of thinking in the direction of moving on to succeeding and developing. This stage is the next step in the process of self-recognising their own limitations of students. This stage consists of the following steps:

**Step 7.** The teacher will give students problems similar to the old one but with a higher degree of difficulty and ask the students to complete in a shorter time period.

**Step 8.** The students self-evaluate the development level of thoughts.

**Step 9.** The teacher will ask the students to use a learning diary (including self-evaluation forms) to record the steps of development throughout each studying period.

*Example: The teacher asks the student to fill in the learning diary according to the following table:*

| Date | Learing content | The number of solutions used | The incomplete content | Limiations and imperfection that needs to be corrected | Limitations and impefections that had been corrected |
|---|---|---|---|---|---|
| | Question 1. | | | | |
| | Question 2. | | | | |
| | Question 3. | | | | |

*2.5.4. Tools for the evaluation of critical thinking ability in chemistry when organising multiple-dimensionalising thinking activities*

Based on the research of the structure and expressions of critical thinking ability in chemistry and the method of organising multiple-dimensionalising thinking, the author has designed and used the evaluation observation table as below:

**TABLE FOR THE EVALUATION AND OBSERVATION OF THE CRITERIAS FOR EVALUATING CRITICAL THINKING WHEN ORGANISING MULTIPLE-DIMENSIONALISING ACTIVITIES**

High School Name.....

Day .....Month.....Year ..... Teacher's name.....

Observation target: Class....., group.....

Lesson name.....

| **No.** | **Criteria expressing critical thinking in chemistry of student** | **Level of achievement in activity** | | | | **Comment** |
|---|---|---|---|---|---|---|
| | | **0** | **1** | **2** | **3** | |
| **1** | Analysed the rules, the mechanism, the principles in each objectives. | | | | | |
| **2** | Reasoned for each solution of the learning objectives. | | | | | |
| **3** | Identified the answer for each learning objectives. | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| **4** | Self compare, analyse, evaluate the limitations in their thinking. | | | | | |
| **5** | Proposed scientific arguments (example, results, answers,..) to proof the limitations in their own thinking. | | | | | |
| **6** | Proposed methods to correct limitations in their own thinking. | | | | | |
| **7** | Self-proposed many solutions to improve their thinking. | | | | | |
| **8** | Self-select the best solution to improve their thinking. | | | | | |
| **9** | Proceed with the best plan. | | | | | |
| **10** | Self-adjust or replace the steps required when performing plan. | | | | | |
| **Conclusion** | **Total number of marks: /30**<br>**Evaluation scale**<br>From 0 to 5: Have not formed critical thinking for chemistry<br>From 6 to 14: Is forming critical thinking for chemistry<br>From 15 to 23: Is developing critical thiking for chemisy<br>From 24 to 30: Critical thinking for chemistry had been perfected. | | *Notes:*<br>*0: did not perform;*<br>*1: perform wrong;*<br>*2: perform correctly but incompletely;*<br>*3: perform correctly and completely.* | | | |

## 3. Practical pedagogical experiment

To evaluate the efficiency and efficacy in the development of critical thinking in chemistry for high school student, the author had performed 6 practical pedagogical experiments (12 main lessons) at 11 high schools in the following cities and provinces: Ho Chi Minh City (2 schools), Long An (2 schools), Ben Tre (2 schools), Dong Nai (2 schools), Tay Ninh (2 schools), Binh Duong (1 school).

***Table 2.*** *The school name, class, number of participating students, contents, the time period of the pedagogical experiment*

| **High school name - County** | **Class** | **Number of participating students** | **Content of the pedagogical experiment** | **The time period of the pedagogical experiment** |
|---|---|---|---|---|
| Le Hong Phong– Ho Chi Minh City | 10AB1 | 44 | 1. Structure of the atom<br>2. Electron shells and layers<br>3. The changing metallic and nonmetallic properties of elements – The periodic law | Semester 1: 9/2016 – 11/2016 (Experiment with the lessons: 1, 2,3,4) |
| Vo Van Kiet– Ho Chi Minh City | 10A7 | 42 | | |
| Tan An– Long An | 10A6 | 40 | | |
| Vinh Hung High School – Long An | 10A3 | 36 | | |
| Nguyen Dinh Chieu– Ben Tre | 10A12 | 39 | | |
| Vo Truong Toan– Ben Tre | 10A4 | 35 | | |

| | | | | |
|---|---|---|---|---|
| Ngo Quyen– Dong Nai | 10A9 | 42 | 4. Chemical bonds<br>5. Chlorine<br>6. Sulfuric Acid | Semester 2: 3/2017 – 4/2017 (Experiment with the lessons: 4, 5,6) |
| Nam Ha – Dong Nai | 10A5 | 51 | | |
| Le Quy Don – Tay Ninh | 10A6 | 43 | | |
| Tran Dai Nghia – Tay Ninh | 10A4 | 44 | | |
| An My- Binh Duong | 10A9 | 35 | | |

The practical pedagogical experiments were performed in the periods before and after applying the multiple-dimensionalising thinking activities, in short before implementation (BI) and after implementation (AI). In each period, the students will perform 1 multiple choice essay quiz to evaluate ability with a grading scale of 30. This is the basis the author uses to evaluate the impact of the implementations of the multiple-dimensionalising thinking activities towards the development of critical thinking ability in chemistry of students. The results are shown in table 2 below:

***Table 3.*** *The statistics of the class performing the practical pedagogical experiemnt at two periods BI and AI*

| | **Average grade** | **Standard deviation** | ***p-values of Chi – Square*** | ***p-values of T – test*** | **ES** | |
|---|---|---|---|---|---|---|
| | | | | | **Value** | **Level of impact** |
| BI | 13.43 | 15.21 | $9.51717.10^{-6}$ | $6.547.10^{-5}$ | 0.84 | Large |
| AI | 26.21 | 14.69 | | | | |

Table 2 shows the p-value of T-test was smaller than 0.05 and the Chi-Square Verification Test gave a result of $\chi^2 = 1273,337 > \chi^2_{(57-1)(57-1),0,01} = 29,706725$ and (p) Sig. $= 9,51717.10^{-6} < \alpha = 0,01$. Through which we can see the distribution in grade of ability between the 2 quizzes before (BI) and after (AI) is due to the effect of the multiple-dimensionalising thinking activities and not random. Furthermore, the ES value of 0.94 shows the large effect of these activities toward the development of critical thinking abilities of students.

## 4. Conclusion

Based on the theoretical research about: the viewpoints, expressions of critical thinking, the author had identified the structure and expressions of critical thinkning in teaching chemistry, from which the author proposed the solution of multiple-dimensionalising comprehension of student in the teaching of grade 10 chemistry. The activities of multiple-dimensionalising comprehension shows the ability to think on multiple dimension (consider, evaluate the problem from multiple angles and aspects) and the ability to self-adjust and self-change of students to comply with different assignment/learning objectives. The result of the practical pedegogical experiment at 11 high schools in different parts shows the efficiency and the efficiacy of multiple-dimensionalising of the learner was maintained. The author hopes that this method can be deploy in following teaching periods.

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