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Feasibility Analysis of Thermochemistry Senior High School Chemistry Textbook Based on Criteria of Four Steps Teaching Material Development Method

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Abstract: This study was conducted to analysis properness of thermochemistry teaching material in chemistry school textbook which is used in most SMA/MA in Kota Bandung based on criteria of selection stage of Four Steps Teaching Material Development (4STMD) method. The type of research is evaluative research by content analysis method. There are three criteria in the selection process of 4STMD method. First is conformity with the curriculum, it is known that object of research is not yet fully in accordance with the demands of the Curriculum. In terms of material broadness, there are four concepts required by the curriculum that are not included in the teaching material, so that the teaching material is less broad. In addition, there are six concepts that are not required by the curriculum, but included in the material, so that the material is too broad. Thus, in general, the material broadness is not in accordance with the demands of the Curriculum. Meanwhile, in terms of concepts depth, from 31 concepts demanded by the curriculum, 18 concepts are less deep and three concepts are too deep. Based on second criteria, that is scientific correctness of the concepts, it is known that there are two concepts that are not scientifically correct according to references from international general chemistry textbooks and books published by IUPAC. Based on the third criterion, namely the cultivation of pedagogical context, it is known that the values and skill embedded in the material are religious values, creativity, curiosity, respect for achievement, responsibility, reading-interested, discipline, and environmental care.

Keywords: Chemistry school textbook; Criteria of selection step of 4S TMD method; Thermochemistry

Introduction

A coherent education system can be a measure of student success in understanding a problem and the material presented by the teacher (Atuhurra et al., 2022). One of the subjects studied by students is natural science education (Serevina et al., 2018). Conceptual integration is a skill that students use as a prerequisite for knowledge in certain sciences when studying a concept or topic in other science subjects (Hamza et al., 2022; Tuysuz, 2016; Uum et al., 2016).

The chemistry in High School (SMA) or Madrasah Aliyah (MA) which is considered difficult and abstract by students is thermochemistry (Ayyildiz et al., 2012; Goedhart et al., 2002; Griffin, 2021; Yalçınkaya et al., 2009). This statement is supported by the fact that many difficulties and misconceptions of students are found as in various chemical education journals which is an indication that this material is indeed difficult. The difficulty of understanding thermochemistry is caused by students' lack of understanding of stoichiometry as prerequisite materials (Zakiyah et al., 2018).

There have been many studies, both conducted in Indonesia and in other countries, what has been done to uncover the difficulties and misconceptions of students on this subject. Some of the results of research on these difficulties include that (1) students have difficulty distinguishing heat and temperature (Kesidou et al.,

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1993; Niaz, 2006; Yalçınkaya et al., 2009), (2) students have difficulty identifying systems and environments on reactions that take place within calorimeters (Yalçınkaya et al., 2009), and (3) students have difficulty identifying exothermic and endothermic reactions (Inayah, 2003; Yalçınkaya et al., 2009). Meanwhile, some research results regarding student misconceptions show that (1) students consider the enthalpy formation and ΔH, are the same thing (Yalçınkaya et al., 2009), (2) students assume that single bonds have the highest bond energies (Rosalyn, 2012), and (3) students consider that bond breaking is an exothermic process and bond formation is an endothermic process (Yalçınkaya et al., 2009).

Difficulties and misconceptions possessed by students hinder the further learning process (Dahar, 2011; Darmana et al., 2013; Nakhleh, 1992; Yalçınkaya et al., 2009). Therefore, students need to understand the thermochemical material first before studying the next material. In addition, thermochemical material must be understood correctly, because it is very closely related to everyday life. Therefore, students' difficulties and misconceptions must be overcome. One way to do that is to improve the quality of learning.

The quality of learning is determined by the quality of each of the main components of the teaching and learning process, namely teachers, learners (students), and teaching materials (Anwar, 2023). One type of teaching material that is widely used in schools is printed textbooks (Swanepoel, 2010). The results of a survey conducted in several public SMA/MA in Bandung, showed that all SMA/MA used certain chemistry textbooks for learning chemistry. Unfortunately, chemistry textbooks for students used in schools have been criticized a lot, especially in explaining chemical concepts (Anwar, 2023). This statement is supported by the results of the Metaphysics research (2014) on the solubility of materials in three high school chemistry textbooks, which states that the concepts in the three books have the potential for misconceptions and are described incorrectly.

The textbooks used in schools have been selected by the Center for Books and Curriculum. Some aspects that are assessed are conformity with the curriculum, correctness of concepts, aspects of language, and graphics. However, there are still problems regarding the correctness of the concept. Therefore, another perspective is needed to assess the quality of textbooks, viewed from the side of the truth of the concept. Another perspective that can be used to assess the quality of textbooks is the criteria used in the development of teaching materials using the Four Steps Teaching Material Development (4S TMD) method. The 4S TMD method is a method of developing teaching materials which consists of four stages, namely selection, structuring, characterization, and reduction (Anwar, 2023). This method is based on the criteria of ideal teaching materials according to Anwar (2021). These criteria are: (1) The scope is in accordance with the curriculum; (2) The concepts in it are scientifically correct; (3) Develop substantial context and pedagogical context; (4) Systematic in its presentation following the "body of knowledge" of science by considering the didactic aspects; (5) Provide assistance to students to learn meaningfully; (6) In accordance with the psychological development and thinking of students; (7) The concepts in it are the essential concepts that must be mastered by students; (8) The explanation of the texts are understood by students easily.

These criteria are the criteria for the four stages of the 4S TMD method. The selection stage is carried out to meet criteria number one to three. Meanwhile, the structuring stage is carried out to fulfill criteria number four and five. Then, the characterization and reduction stages were carried out to fulfill criteria number six and eight. The criteria used in this study were the criteria at the selection stage, namely the criteria for conformity to the applicable curriculum, scientific truth of the concept, and the development of content context and pedagogic context. The criteria for conformity to the curriculum are carried out by comparing the concepts contained in the textbooks with the demands of the curriculum. To see if it meets the criteria for the correctness of the concept, it is done by comparing a concept with the standard concept obtained from international general chemistry textbooks. These books are used as a source in determining standard concepts, because the concepts contained in these books are guaranteed to be true. Based on this background, this research was conducted to analyze the correctness of the concept of thermochemistry teaching materials in the 2013 curriculum for high school/MA textbooks from the perspective of 4S TMD.

Method

The research method used is a descriptive research type documentary research. The object of the research is a thermochemical material manuscript in the Chemistry school textbook for SMA/MA Class XI by the author A publisher B. The book was selected based on the results of a survey on the use of class XI chemistry textbooks in 27 of the 29 public high schools/MA in the city of Bandung.

In this study, material analysis was carried out in terms of the truth of the concept. The truth of the concept is defined as the conformity of a concept with the standard concept. The standard concepts are taken from nine general chemistry textbooks, six physical chemistry textbooks, and books published by the International Union of Pure and Applied Chemistry (IUPAC) such as

Green Book (Cohen et al., 2008) and Gold Book (IUPAC, 2014).

The first stage, the identification of knowledge on the object of research, is carried out using discernment techniques whose guidance is the definition of every type of knowledge except metacognitive knowledge, according to Anderson et al. (2001). Then, the second stage, namely concept selection, is carried out to separate the concept (declarative knowledge) with procedural knowledge. The next stage is the identification of concepts in general chemistry textbooks, carried out using assessment techniques whose guidance is concept data on research objects. The next stage, the analysis of concepts in general chemistry textbooks, is carried out on concepts conveyed differently in the nine books. The last stage is the analysis of the truth of concepts on the object of research, carried out by comparing each knowledge that constructs each concept with its standard knowledge.

Result and Discussion

The first step in this analysis stage is to identify knowledge. The results show that there are 87 knowledge that explain 32 chemical concepts in the research object. The second step is concept selection, obtained 87 knowledge of which 72 is declarative knowledge. In other words, in the object of research there are 32 concepts that are constructed by 72 knowledge. These concepts are constructed by declarative knowledge presented with propositions, while the topics of energy diagrams (enthalpy diagrams) and energy cycles (Hess cycles) are identified as concepts, because both concepts use the form of presenting mental image knowledge, although these two topics can also presented in the form of a proposition. Presentation in the form of mental images (diagrams) is more practical than presentation in the form of propositions. Meanwhile, declarative knowledge in the form of facts is not selected even though it is presented in the form of a proposition because it is certain that the truth is true.

Then, the concept identification step in the chemistry textbook showed that of the 32 concepts constructed by 72 knowledge's that had to be identified, there was one concept, namely the energy cycle, which was not conveyed, so this concept was taken from the physical chemistry textbook written by Monk (2004). Concept analysis in nine general chemistry textbooks showed that 10 of the 32 concepts in some of these books were conveyed differently or contradicted by several other books. The ten concepts are thermochemistry, heat, system and environment, exothermic reactions, endothermic reactions, energy diagrams, standard states, constant volume calorimeters, constant pressure calorimeters, and bond dissociation energies (D). The following is a more in-depth analysis of 4 of the 10 concepts.

Thermochemistry

In the nine common chemistry textbooks used there are three different thermochemical concepts, namely:

Table 1. Thermochemical Concepts in General Chemistry Textbooks

1	2	3
Thermochemistry studies the heat changes involved in chemical reactions	Thermochemistry studies the heat involved in chemical changes and physical changes	Thermochemistry is the study of the relationship of chemistry with energy
Chang et al. (2011), Jespersen et al. (2012), Brown et al. (2012), Ebbing and Gammon (2007), Ebbing et al. (2007), and Petrucci et al. (2006)	Silberberg (2007) and Whitten et al. (2004)	(Tro, 2014)

As seen in the table, concept 1 states that thermochemistry studies the heat changes involved in chemical reactions, while concept 2 mentions that not only in chemical reactions, but also in physical changes. After analysis, it turns out that in 4 of the 5 books that state concept 1, there are examples or concepts related to changes in physics. For example, a book written by Chang et al. (2011) in the chapter Energy Relations with Chemical Reactions, uses the terms endothermic and exothermic processes, and presents changes in the form of water as an example of one of the processes. Later, the book written by Brown et al. (2012) on the Thermochemistry chapter, involves the process of condensing water when discussing Hess's law. Furthermore, the book written by Ebbing et al. (2007) in the chapter of the same title, involving the concept of the heat of melting, ΔHfus, the heat of evaporation, ΔHVap and the heat of sublimation, ΔHsub as well as examples of each process. Finally, the book written by Petrucci et al. (2006) in the chapter of the same title, has a subbab entitled Enthalpy Change (ΔH) Which Accompanies the Process of Change in the Form of Substances.

The existence of these examples or concepts in the four books seems to contradict the thermochemical definition. In fact, given that the books were written by experts, the possibility of contradictions is very small. Therefore, most likely, the authors of concept book 1 have the view that chemical reactions are always accompanied by physical changes. For example, a chemical reaction that takes place, either in an isolated or isolated system, will inevitably result in a change in the temperature of the system (temperature change is an example of a physical change). So based on this view, in concept 1, the author also implicitly states that thermochemistry studies the energy involved in physical changes, so that the existence of examples or concepts related to physical changes in the books does not contradict the definition of thermochemistry. So basically, concept 1 with concept 2 is the same. However, because in concept 1 there is no written explanation of this view, then concept 2 is preferred over concept 1. Then, when compared with concept 3, then the thermochemical definition in concept 2 is more specific. In concept 3 it is mentioned that thermochemistry is the study of the relationship of chemistry with energy. The use of the word energy indicates that the definition is still common because there are many forms of energy. One example is electrical energy. The relationship of chemistry to this form of energy is not studied in thermochemistry, but in electrochemistry. So based on the results of this analysis, concept 2 is preferred over concept 3 to be used as a standard.

Heat

The results of the analysis of the concept of heat in each book show the existence of two different definitions of heat, namely:

Table 2. Definition of Heat in General Chemistry Textbooks

	1	2
Concept	Heat is the transfer of heat energy from one object to another whose temperature is different	Heat is kinetic energy (also called heat energy) that moves from one object to another as a result of the temperature difference between the two.
Textbook Sources	Chang et al. (2011), Tro (2014), and Zumdahl et al. (2007)	Silberberg (2007), Whitten, et al. (2004), Jespersen et al. (2012), Brown et al. (2012), Ebbing et al. (2007), and Petrucci et al. (2006).

The table shows that in definition 1, heat is defined as a process, while in definition 2 heat is defined as a noun. In the book Physical Chemistry written by Levine (2009), it is explained that "Heat and work are forms of energy transfer rather than forms of energy". In another physical chemistry textbook, Atkins et al. (2006) also explain that "... it must never be forgotten that heat is a process (the transfer of energy as a result of a temperature difference), not an entity". Both explanations compare the definition of heat as a process with the definition of heat as a noun, and clearly state that the definition of heat as a process is a more precise definition. However, according to IUPAC, the error in assuming heat is a form of energy, can still be justified if there is information that this form of energy only appears when a process takes place. This can be seen from the definition of heat in the Gold Book (IUPAC, 2014) which is energy that moves from objects with a hotter temperature to objects with a cooler temperature due to temperature differences. So, when there is no process due to the absence of a temperature difference, then there is no heat. Thus, based on these considerations, both definition 1 and definition 2 are used as standard concepts.

Systems and Environment

The definition of system and environment in the nine books used is the same. Although the definition of system and environment in these books is the same, the definition of system and environment is different for reactions involving solutions. This can be seen from the examples given in these books. The table below contains examples of different interpretations of the system and the environment when studying chemical reactions between two solutions that take place in a beaker.

Table 3. Determination of Systems and Environments in Reactions Involving Solutions in General Chemistry Textbooks

System	Environment	Textbook Sources
Reagents and Products	Solvents, Chemical Glasses, Laboratories, and other things outside the system	Whitten et al. (2004), Brown et al. (2012), and Tro (2014)
Substances or mixtures present in a container. In this case it is both solutions that react (including solvents)	Chemical Glasses, Laboratories, and other things outside the system	Silberberg (2007), Jespersen et al. (2012), Ebbing et al. (2007), and Zumdahl et al. (2007)
A container containing a substance or mixture, in this case a beaker containing both reacting solutions	Laboratories and other things outside the system	Chang and Overby (2011) and Petrucci, et al. (2006)

The table shows that the difference in the determination of "environment" is caused by the difference in the determination of "system". In determination 1 it is stated that only the reactants and products are the system, while the solvent and others are classified as the environment. Determination 2 states that the solvent is still classified as a system, so the environment starts from the beaker where it reacts, the laboratory, and others outside the system, while determination 3 states that the beaker is still included in the system. So, the system in determination 1 is narrower than the system in determination 2 which is narrower than determination 3.

Levine (2009) explains that "A chemical system can be studied from either a microscopic or a macroscopic viewpoint". Thermochemistry is part of thermodynamics which is a macroscopic science (Levine, 2009). Therefore, the definition of the system more specifically is "The macroscopic part of the universe under study in thermodynamics" (Levine, 2009). Mahan (1975) also explained that "Thermodynamics only relates to the properties of bulk matter to its behavior in physical and chemical process". Based on this explanation, it can be concluded that determination 1 is the determination of the system based on a microscopic view because it separates the reagents and products from the solvent, while the determination of 2 and 3 is the determination of the system based on a macroscopic view. Because thermodynamics is a macroscopic science, determination 1 will not be chosen as a standard concept.

In determination 2, the container in which the reaction takes place is considered as the environment, while in determination 3 the container is considered as the system. Regarding this matter, Mortimer (2008) explains and gives an example of determining the system and environment when a gas reacts in a piston cylinder and immersed in a water bath, "We must specify exactly what parts of the universe are included in the system. In this case we define the system to consist only of the gas. The cylinder, piston, and constant-temperature bath are parts of the surroundings". Based on this explanation, the container is part of the environment, therefore, the determination that will be used as a standard concept is the determination of 2.

Fixed Volume Calorimeter

Based on the results of an analysis of the fixed volume calorimeter concept, it was found that there were differences regarding the determination of the system and the derivation of the mathematical equation for calculating the heat of reaction among the nine books used. This section will only discuss the differences in system determination.

Previously, in the concept of the system and environment in point 3, it was discussed about determining the system in a reaction involving a solution and resulted in the conclusion that the solvent belongs to the system, while the container in which the reaction takes place is the environment. A fixed volume calorimeter is used to determine the heat involved in a reaction involving a gas, therefore the difference in determining the system is different from the difference in determining the system for a reaction involving a solution. The difference in determining the system for this concept can be seen in Table 4.

In this type of calorimeter, the reaction takes place inside the bomb calorimeter. Therefore, the bomb calorimeter can be regarded as a vessel where the reaction takes place, which in the previous discussion has been concluded as part of the environment. Therefore, the explanation that will be used as a standard concept is the determination of 1.

Table 4. Determination of the System and Environment in the Reaction that Takes Place in Fixed Volume Calorimeter

System	Environment	Textbook Sources
All the substances in the bomb calorimeter	Bomb calorimeter, water in calorimeter and other calorimeter parts	Silberberg (2007), Whitten et al. (2004), Jespersen et al. (2012), Brown et.al. (2012), Tro (2014), Ebbing et al. (2007), and Zumdahl et al. (2007)
Everything in the outermost layer of the calorimeter (bomb device and its contents, water, thermometer, stirrer, etc. The system is isolated from its surroundings	Everything beyond the calorimeter	Chang et al. (2011) and Petrucci et al. (2006)

The next step is the analysis of the truth of the concept on the object of research, resulting in the conclusion that 22 of the 72 knowledge that constructs 17 of the 32 concepts, is declared wrong. In other words, the percentage of the truth of knowledge on the object of research is 69%. Of the 22 knowledge, some of them were declared wrong because they were not the same or in accordance with the standard knowledge and some other knowledge was declared wrong because other knowledge related to the knowledge was declared wrong. The following is a detailed explanation of the errors 4 of the 22 knowledge.

Knowledge 1 and 2

Knowledge 1 and 2, respectively, construct the concepts of exothermic reaction and enthalpy. The difference between these two knowledges and the standard knowledge can be seen in the table 5.

Based on the table, it can be concluded that the error in both knowledge is due to equating heat with heat energy or in other words, considering heat as energy possessed by a substance. In standard knowledge 1, there are two definitions of heat, namely as a form of energy and as a form of energy transfer. In both definitions there is one key word that is the same, namely different temperatures or temperature differences. This keyword clearly shows the error of both knowledge because without a temperature difference that will cause a process to take place, there will be no heat. In other words, a substance does not have a heat content, but has an energy content as written in standard knowledge 2.

Table 5. Comparison of Knowledge 1 and 2 with Standard Knowledge

Concept in School Textbook (Page)	Standard Concept
In an exothermic reaction, the heat content of the system will decrease. (63)	Heat is the transfer of heat energy between two objects with different temperatures (Chang et al., 2011). Another definition: Heat is energy that moves from a hotter object to a colder object due to a temperature difference (IUPAC, 2014). Other general chemistry textbooks also show the same definition as one of the above definitions
Enthalpy can simply be called the heat potential of a system or the heat content of a substance. (61)	... the enthalpy, or 'energy content' of the substance formed is taken from the enthalpy of the substance consumed (Whitten et al., 2004)

Knowledge 3

Knowledge 3 constructs work concepts (w). The table below shows the difference between this knowledge and the standard knowledge.

Table 6. Comparison of Concept 6 with Standard Concept

Concept in School Textbook (Page)	Standard Concept
Work on a system is the product of the pressure (P) and the change in volume (ΔV). $w = P \times \Delta V$ (60)	Work in the process of expansion or compression is called pressure–volume work (or P–V work). When the process takes place at constant pressure, the signs and magnitudes of this type of work are: $w = -P \times \Delta V$ where P is the pressure and V is the change in volume, V_end-V_initial (Brown et al., 2012). Similar knowledge is also found in eight other commonly used chemistry textbooks.

In the table, it can be seen that the difference between these two knowledges is in the mathematical equations of their work. In knowledge 3, the equation is not negative. In fact, as seen in standard knowledge, the equation should have a negative sign. The negative sign in the equation w is an adjustment to the results of the agreement of scientists. Scientists agree on a rule regarding the sign w, which is negative when the system does work and positive when the system is subjected to work. For example, when a system expands, the system is said to be doing work and therefore the value of its work must be negative. In the expansion process, the final volume of the system is greater than the initial volume of the system, thus the change in volume (ΔV) is positive. If the pressure (P) and V are positive, then w will also be positive. That is, it is not appropriate or violates the agreed rules. Therefore, so that the work value is in accordance with the agreed rules, a negative sign is added to the mathematical equation (w=-P×ΔV). This description also applies to systems that are subjected to work or are subjected to compression.

Table 7 contains the derivation of the mathematical equation w. Based on the table, it can be concluded that the absence of a negative sign in the mathematical equation of work in knowledge 3 can result in a misinterpretation of whether the system performs or is subjected to work. Therefore, this knowledge is declared false.

Table 7. Determination Mathematical Equations of Work

Expansion	Compression
At the time of expansion, the system is said to be doing work. Then the work value must be negative. ↓ At the time of expansion: V_end>V_beginning, so the value of V is positive. If the value of V is positive and the value of w must be negative, then the pressure value (P) must be negative. $w = P \times \Delta V$ $(-) = (-) \times (+)$ ↓ Since there is no negative pressure value, the negative sign must be written in the mathematical equation: $w = -P \times \Delta V$	When compressed, the system is said to be working. Then the work value must be positive. ↓ At the time of expansion: V_end>V_beginning, so the value of V is positive. If the value of V is positive and the value of w must be negative, then the pressure value (P) must be negative. $w = P \times \Delta V$ $(+) = (-) \times (-)$ ↓ Since there is no negative pressure value, the negative sign must be written in the mathematical equation: $w = -P \times \Delta V$

Knowledge 4

Knowledge 4 constructs the concept of heat (q). The table 8 shows the difference between this knowledge and the standard knowledge.

The derivation of the mathematical equation of heat at constant pressure in knowledge 4 is the same as in standard knowledge. However, this knowledge is wrong because it assumes that in a reaction that takes place at constant pressure (and of course, in a closed system), a change in volume results in the system compressing the surroundings (doing work). Volume changes occur in reactions involving gases. At constant pressure, the change in volume that causes the system to do work only occurs if the number of moles of gaseous products is greater than the number of moles of reactants in the gaseous state. If the number of moles of product in the gaseous state is less, then the system will experience a decrease in volume or experience compression (subject to work). Therefore, the value of w in the derivation of the equation can be positive. If the value of w in the equation is positive, then

ΔU=q+w=q_p+PΔV so that, 〖q〗_p=ΔU-PΔV

The mathematical equation for heat of reaction at constant pressure (q_p) when the value of w is positive is not the same as the mathematical equation of q_p when the value of w is negative. In fact, the mathematical equation q_p should be applicable, both when the value of w is negative or positive. This knowledge error is caused by an error in knowledge 3, namely an error regarding the sign in the general mathematical equation for work.

Table 8. Comparison of Concept 7 with Standard Concept

Concept in School Textbook (Page)	Standard Concept
If a chemical reaction takes place at constant pressure, a change in volume can result in the system compressing the environment (doing work) so that it applies: $\Delta U = q + w$ $\Delta U = q_\text{p} - P\Delta V$ or $q_\text{p} = \Delta U + P\Delta V$ *The subscript "p" indicates that the process occurs at constant pressure*. (60)	The definition of enthalpy, H is $H = E + PV$ For processes at constant temperature and pressure: $\Delta H = \Delta E + P\Delta V$ We know that $\Delta U = q + w$, so: $\Delta H = q + w + P\Delta V$ At the constant pressure, $w = -P\Delta V$, so: $\Delta H = q + (-P\Delta V) + P\Delta V$ $\Delta H = q_\text{P}$ (Whitten, et al., 2004). Similar knowledge is also found in eight other commonly used chemistry textbooks.

From the twenty-two knowledges that were declared incorrect, 41% of them were knowledge of terminology (PF 1), 27% of specific details and elements (PF 2), 14% of principles and generalizations (PK 1), 9 % about classification and categorization (PK 2), and the remaining 9% is knowledge about theory, model, and structure (PK 3).

Conclusion

In the Chemistry school textbook for SMA/MA Class XI by author A, publisher B, there are 22 of 72 knowledge that constructs 10 of the 32 concepts that are declared incorrect based on references to general chemistry textbooks, physical chemistry, and/or IUPAC books. If made in the form of a percentage, then the percentage of the truth of knowledge on the material is 69%. Then, because the concepts in textbooks must be scientifically correct, the standard concepts from the analysis in this study can be used as material for writing books (teaching materials) because they are identified from books that are guaranteed to be true. For further research with the same research object, it can be analyzed from the perspective of the 4S TMD criteria at the next stages, namely structuring, characterizing and didactic reduction

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