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Didactic Modes of Scientific Experiments in Moroccan High Schools: Photosynthesis as an Example

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Abstract: This exploratory study aims to verify whether the current use of scientific experiments in the Moroccan high-school science curriculum meets students' needs for experimental scientific learning. For that purpose, a sample chapter of the official science textbook was analysed in detail. The analysis was carried out using a didactic model of the French didactician Coquide, which categorizes teaching objectives into three modes: practical familiarisation, empirical investigation and conceptual construction. Analysis grids were built based on a selection of the three didactical modes' attributes. These grids were used to identify the presence and the weight of these three didactical modes within the chosen sample chapter. Results reveal that experiments in the high-school scientific curriculum are not presented in a balanced way and rarely implemented according to a didactic logic. The study also shows that the experiments analysed are essentially focused on the conceptual construction mode while neglecting practical familiarisation and empirical investigation.

Keywords: *Scientific experiment, didactical types, typology of experiments.*

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Introduction

A scientific experiment involves a question that calls for a systematic research, a test centred on a generally hypothetical situation and results leading to a new knowledge (Coquide, 2000; Develay, 1989). It is also usually accompanied by a manipulation in which sensory-motor skills and instruments play a significant role (Bernard, 1865). Furthermore, in the definition of the scientific experiment concept, it is possible to extend the concept of experiment to the fields of geology (Chakour et al., 2019) and astronomy, which essentially proceed by observation and field investigation. It is even possible, in extreme cases, for the experimental test procedure to be completely replaced by an "intellectual experiment" (Dubarle, 1965), which does not affect the validity of the experimental reasoning.

Besides, the scientific experiment plays an important role in the teaching of science to high-school students. Indeed, scientific experiments bring reality closer to learners' understanding by putting them into a research or demonstration process leading to concept construction and knowledge acquisition (Zalta, 2019). In addition, the scientific experiment allows learners' reasoning abilities to develop, ultimately resulting in a generation capable of using scientific reasoning as an effective problem solving tool (Galiana, 2003).

It is therefore difficult to imagine a science curriculum devoid of scientific experiments. Consequently, the Moroccan Ministry of National Education issued strong recommendations on the importance of scientific experimenting and also provided high schools laboratories with the adequate equipment needed to conduct these experiments (Official Program, 2007).

However, due to the difficulty of accessing theoretical frameworks that are intelligible and capable of generating operational models and procedures, the Moroccan scientific educational system generally follows the French system,

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which also faces criticism. Specifically, the latter does not exploit all the epistemological and didactic studies that consider experimental thinking and practice from the perspective of recent scientific and pedagogical paradigms (Coquide, 2000).

In addition to this shortcoming of the curriculum, the inclusion of content inherited from increasing Cartesianism and transmissive pedagogical trends confines the French experimental system to the service of conceptual construction only, as pointed out by Giordan (1978) and Astolfi (1978). This idea was subsequently re-examined and applied to experimental teaching by Coquide (2003). Indeed, Coquide showed that high-school science education uses experimental work primarily for conceptual development while intentionally neglecting experimental techniques and methodology (Coquide, 2000).

Interestingly, the Moroccan educational system focuses rather on the contents, which would suggest that experimental pedagogy may focus on the conceptual construction while marginalising important objectives related to experimental reasoning learning as well as to experimental techniques' initiation.

The aim of this research is to verify whether Moroccan experimental practice reconciles, in a balanced and logical way, the functional variety of scientific experiments in the teaching of science in Moroccan secondary schools. The research questions are as follows:

- ✓ Which didactic modes of scientific experiments can be detected in Moroccan science textbooks?
- ✓ Are these didactic modes programmed in a logical and balanced way?

Didactic modes of experimental activities

Based on a multitude of European research papers related to the use of scientific experiments within classes and especially those of practical work, the French researcher Coquide (1998) tried to design a tool in the form of a typology of experiments derived from a set of objectives and functions that scholars have attributed to the scientific experiment. In this model, she was inspired by Astolfi's typology (1991) that categorizes the different types of teaching-learning situations. The Astolfi's (1991) typology is as follows: Order by the situation; Order by the method; Order by knowledge; Order by the obstacle and Order by production.

Coquide noted that the objectives, functions and pedagogy of scientific experiments focus on the first three orders of Astolfi (1991) that are Order by the situation; Order by the method and Order by knowledge. Therefore, her typology of didactic modes of scientific experiments comes as follows: Practical familiarization mode; Empirical investigation mode and Theoretical elaboration mode.

These three didactic modes are characterized by three different types of input that are in the same order: an entry by the student (or the situation (Astolfi, 1991)); an entry by the method and an entry by conceptual knowledge.

The characteristics and examples of these teaching modes as mentioned in Coquide's (1998) research are :

a. Practical familiarisation mode (field of experimentation–action)

In this mode, the experiments' purpose is to familiarise the learner with the studied objects and phenomena. Experiments that are representative of this didactic mode include the following: visual experiments, experiments of exploration, experiments of familiarisation, and introductions to new materials. Experiments where the teacher plans to expose misconceptions and correct them can also be added to this mode.

In addition, this mode offers learners the chance to enrich their empirical knowledge with techniques and procedures that can be mobilised in future situations. It also helps them to acquire curiosity and a constantly questioning attitude, as well as observation and investigation skills.

The mode of practical familiarisation can be observed in primary education. However, researchers believe that it is essential at all academic education levels due to its ability to install scientific attitudes among learners (Coquide, 2000).

b. Empirical investigation mode (field of experimentation–object)

This mode relates to the methodological training in the field of experimentation through the effective and free exercise of experimental reasoning. It is also more time consuming than the practical familiarisation mode. Consequently, the empirical investigation mode can be at a disadvantage compared with the practical familiarisation mode due to time constraints on the teaching schedule.

Furthermore, this didactic mode requires the acquisition and mastery of experimental methodological skills through two consecutive pedagogies. The first pedagogy allows the acquisition of procedures and experimental concepts separately by providing the learner with all the mastery conditions (a pedagogy that is not necessarily fixed). The second pedagogy calls for situations in which acquired methodological and conceptual resources are mobilised in the

resolution of genuine problems while avoiding all pre-established procedures (OHERIC* for example) (Giordan, 1992; Cariou, 2010).

Examples of resource management situations belonging to this mode are the extraction of problems from analytical studies of preliminary data and the induction–deduction of hypotheses from interactions between preliminary data, theoretical generalisations and problematic elements. Other examples include the establishment of an experimental plan for verifying a hypothesis, the design of experimental protocols, the understanding of causal relations and the construction of explanatory models.

c. Theoretical elaboration mode (field of experimentation–tool)

The function that this didactic mode fulfills, as its name indicates, is the construction of theoretical knowledge, as well as the demonstration and extension of the scientific concepts' validity and illustrations. That is why Coquide (2000) identified it as the experiment's tool. Some of the representative formulas of this experimental model of concept construction are as follows: illustration experiments, demonstration experiments, reference experiments, concept expansion experiments, and modelling experiments. Furthermore, Astolfi (1998) attributes to this didactic mode the role of using concepts in new experimental situations in order to give these situations the character of operational and functional knowledge, and to widen the mode's field of validity. In addition, according to Galiana (1999), the behavioural content of this didactic mode can only be cognitive and intentionally gives a place to psycho-motor and emotional content.

The theoretical elaboration mode allows the appropriation of scientific concepts through experimental situations; except that, it does not escape the misconceptions that arise unintentionally during the transmission of knowledge (Metioui et al., 2016; Svandova, 2014).

These misconceptions can have several origins that can be linked to the teacher (Urey, 2018), the subject or to the method.

Methodology

Research Goal

This paper is a qualitative research which aims to explore the scientific textbooks as an official pedagogical tool and to assess its effectiveness in experimental scientific education in Morocco.

The comparison of each didactic mode' results will evaluate the experiments programming's logic within the textbooks and consequently, the teaching and learning process objectives within the Moroccan educational system.

Sample and Data Collection

Since the official curriculum (Official program, 2007) does not explicitly or exhaustively mention the experiments to be conducted, it was decided to use the official textbooks in this research, firstly because these are the only documents that contain all the official experiments; and secondly because their compliance with the official curriculum is scrutinized by committees of scientific and educational specialists before publication.

The first-year textbook of the baccalaureate (level= 11th grade, age of students= 16–17 years) was chosen as our study sample because it offers a large choice of experimental situations. The research was limited to the 'Photosynthesis' unit, which is one of the richest and most diverse in the official textbooks in terms of experiments (18 experiments).

The names and objectives of these experiments as reported in the textbook are presented in Table 1.

Table 1. Photosynthesis experiments and its objectives as stated in the official textbook

The title of the experiment	The objective assigned by the textbook
1. Unicellular green algae in a culture medium	Content introduction and intellectual reflection initiation
2. O ₂ release by an aquatic chlorophyll plant	Demonstration of the O ₂ release under light conditions
3. CO ₂ uptake in green leaves	Demonstration of CO ₂ absorption at the leaf level
4. Factors determining photosynthetic gas exchange	Highlighting the main factors influencing the chlorophyll's gas exchange
5. The unicellular marine algae	Demonstration of O ₂ uptake and CO ₂ emission in light conditions in chlorophyllous plants
6. The relationship between CO ₂ uptake and O ₂ release	Highlighting the role of CO ₂ concentration in the process of photosynthesis
7. Factors influencing the intensity of photosynthesis	Building knowledge on the importance of the temperature level and the brightness in the intensity of the

* Observation, Hypothesis, Experiment, Result, Interpretation, Conclusion

photosynthesis phenomenon

Table 1. Continued

The title of the experiment	The objective assigned by the textbook
8. The conditions of synthesis of starch at the leaf level	Building knowledge on the conditions needed for the production of organic matter in plants
9. CO ₂ and organic matter	Demonstration of CO ₂ as a component of organic matter
10. Extraction of the chlorophyllian pigments	Extraction and demonstration of chlorophyll components
11. The absorption spectrum of chlorophyll pigments	Building knowledge on the absorption spectrum of chlorophyll pigments
12. The change in intensity of photosynthesis as a function of the type of radiation	Demonstration of the photosynthesis intensity variation as a function of absorbed radiation
13. Engelman's experience	Building knowledge on the change in the absorption spectrum and the spectrum of action as a function of the wavelength
14. Hill's experiment	Building knowledge on the origin of the rejected O ₂ during the process of photosynthesis
15. Uribe and Jagendorf's experiment	Highlighting the use of the H ⁺ ion concentration difference between thylakoide and stroma in the ATP production process
16. Calvin's experiment	Building knowledge on the classification of the organic elements produced during the photosynthesis
17. Gaffron's experiment	Highlighting the change in the amount of CO ₂ embodied between the light and dark phases
18. The photochemical phase and the phase of use of CO ₂	Demonstration of the change in intensity of radiation activity in composite organic matter during photosynthesis (APG, RudiP) between light and dark conditions and between the availability or lack of CO ₂ in the medium

Data analysis

An analysis of Coquide's (1998; 2000) and Astolfi's (1991; 1998) research helped to determine the operational components of each didactic mode (practical familiarisation, empirical investigation and conceptual construction). Within each mode, these components refer to the experiment's objectives (Table 2).

Table 2. Operational components extracted from Coquide's didactic modes

	Practical Familiarization	Empirical Investigation	Theoretical Elaboration
Operational components and criteria	The learner explores a new subject	The experiment aims at the conceptualization of the experimental methodology elements as well as the training with the experimental reasoning	The experiment aims at the construction of the concepts and the widening of their fields of validity
	The learner explores and / or uses an instrument for the first time	The experimental work uses metacognitive reasoning	The experiment aims at developing scientific models
	The learner is introduced to a technique	The experiment offers training in the experimental method	The experiment explains the content to convince learners
	The experiment increases the learner's interest in the study subject	The experiment allows the exercise strategies of argumentation and scientific debate	The experiment verifies the accuracy of scientific content
	The experiment enriches the learner's empirical referent	The experiment teaches how to master the formulation of results and experimental conclusions	The experiment is focused on the contents and less on the experimental methodology
	The experiment satisfies the learner's scientific curiosity	The experiment helps to conceptualize scientific attitudes and values	The experiment is a practical work that validates or complements the conceptual content
	The experiment unveils the false conceptions	The experiment emphasises on correcting misconceptions and changing values	The experiment aims at the rectification of false conceptions
	The experiment installs a scientific attitude	The experiment aims at verifying the accuracy of the hypotheses and the debate of the results	The experiment leads to the development of textual or graphical summaries and generalizations

Results

Based on the operational components extracted from the three didactic modes (practical familiarisation, empirical investigation and conceptual construction) in Table 2, three grids (a grid for each mode) in the form of a weighted checklist were subsequently constructed (Tables 3, 4 and 5).

The purpose of the three grids is to analyse the different experimental situations of the study sample. In order to collect the relevant data, the grids were submitted to two teachers and, for objectivity purposes, to an inspector.

The scale used for each operational component is set between 0 and III as follows:

0: Absent

I: Weakly present

II: Moderately present

III: Strongly present

The results are presented in Tables 3, 4 and 5.

Table 3. Experiments analysis for the Didactic Mode: Practical Familiarisation

	Operational components	Experiments																	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Practical familiarisation	The learner explores a new subject	III	I	I	I	0	0	I	I	I	I	I	I	I	I	I	I	I	0
	The learner explores and / or uses an instrument for the first time	0	0	0	0	I	I	0	0	I	II	II	I	I	0	0	II	I	I
	The learner is introduced to a technique	0	I	I	I	I	I	0	I	I	II	I	0	0	I	I	I	0	0
	The experiment increases the learner's interest in the study subject	0	0	0	0	0	0	0	0	0	I	0	0	0	0	0	0	0	0
	The experiment enriches the learner's empirical referent	I	I	I	I	0	0	0	I	I	II	I	0	0	I	I	I	0	0
	The experiment satisfies the learner's scientific curiosity	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	The experiment unveils the false conceptions	II	I	I	0	0	0	0	I	I	0	0	0	0	II	I	I	I	I
	The experiment installs a scientific attitude	I	0	0	0	0	0	0	0	0	0	0	0	0	I	0	0	0	0
	Sum	7	4	4	3	2	2	1	4	5	8	5	2	2	6	4	6	3	2
	Weights (%)	29	17	17	12	8	8	4	17	21	33	21	8	8	25	17	25	12	8

Table 4. Experiments analysis for the Didactic Mode: Empirical Investigation

	Operational components	Experiments																	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Empirical investigation mode	The experiment aims at the conceptualization of the experimental methodology elements as well as the training with the experimental reasoning	I	I	I	I	0	0	0	I	I	0	0	0	0	I	I	I	0	0
	The experimental work uses metacognitive reasoning	0	I	I	I	0	0	0	I	II	0	0	0	0	I	I	I	0	0
	The experiment offers training in the experimental method	0	0	0	0	0	0	0	0	0	I	0	0	0	0	0	0	0	0
	The experiment allows the exercise strategies of argumentation and scientific debate	I	I	I	I	0	I	0	I	I	I	0	0	0	II	II	I	0	I
	The experiment teaches how to master the formulation of results and experimental conclusions	I	I	I	I	I	I	I	I	I	0	0	I	I	I	I	I	I	I
	The experiment helps to conceptualize scientific attitudes and values	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	The experiment emphasises on correcting misconceptions and changing values	0	I	I	I	I	I	0	I	I	0	0	0	0	II	I	I	I	0
	The experiment aims at verifying the accuracy of the hypotheses and the debate of the results	0	I	I	II	0	I	I	I	I	0	0	0	0	II	I	0	I	I
	Sum	3	6	6	7	2	4	2	6	7	2	0	1	1	9	7	5	3	3
	Weights (%)	12	25	25	29	8	17	8	25	29	8	0	4	4	37	29	21	12	12

Table 5. Experiments analysis for the Didactic Mode: Theoretical Development

	Operational components	Experiments																		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
Theory of elaboration	The experiment aims at the construction of the concepts and the widening of their fields of validity	0	III	III	III	II	III	III	III	III	III	I	II	II	III	III	III	III	III	
	The experiment aims at developing scientific models	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	The experiment explains the content to convince learners	0	II	II	II	III	III	III	III	III	III	I	II	II	III	III	III	III	II	III
	The experiment verifies the accuracy of scientific content	0	III	I	II	III														
	The experiment is focused on the contents and less on the experimental methodology	II	III	II	II	III														
	The experiment is a practical work that validates or complements the conceptual content	0	III	I	I	III														
	The experiment aims at the rectification of false conceptions	0	I	I	I	I	I	I	I	I	0	0	0	0	II	I	I	I	I	I
	The experiment leads to the development of textual or graphical summaries and generalizations	0	III	III	III	III	III	II	III	III	I	I	II	II	III	III	III	III	III	III
	Sum	2	18	18	18	18	19	18	19	19	11	8	15	15	20	19	18	18	18	19
	Weights (%)	8	75	75	75	75	79	75	79	79	45	33	62	62	83	79	75	75	75	79

For each experiment, the sum of all the components' scores was calculated. Then, the weight of all components was calculated as a ratio of the sum of all the scores to the maximum score possible (24). These weights' scores were then used to calculate the weighted average of each didactic mode in each experiment examined (Table 6).

Table 6. Didactic Modes weighted average values for each experiment

Didactic modes	Experiments																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Practical Familiarisation	59	15	15	10	9	8	5	14	16	39	32	11	11	17	14	21	12	8
Empirical Investigation	25	21	21	25	9	16	9	21	23	9	18	5	5	26	23	17	12	12
Theoretical Elaboration	16	64	64	65	82	76	86	65	61	52	50	84	84	57	63	62	76	80

These weighted average values were subsequently displayed as co-ordinates in a ternary graph (Figure 1) in order to facilitate the visualisation and interpretation of the results. Within the ternary graph, each pole represents a pure didactic mode.

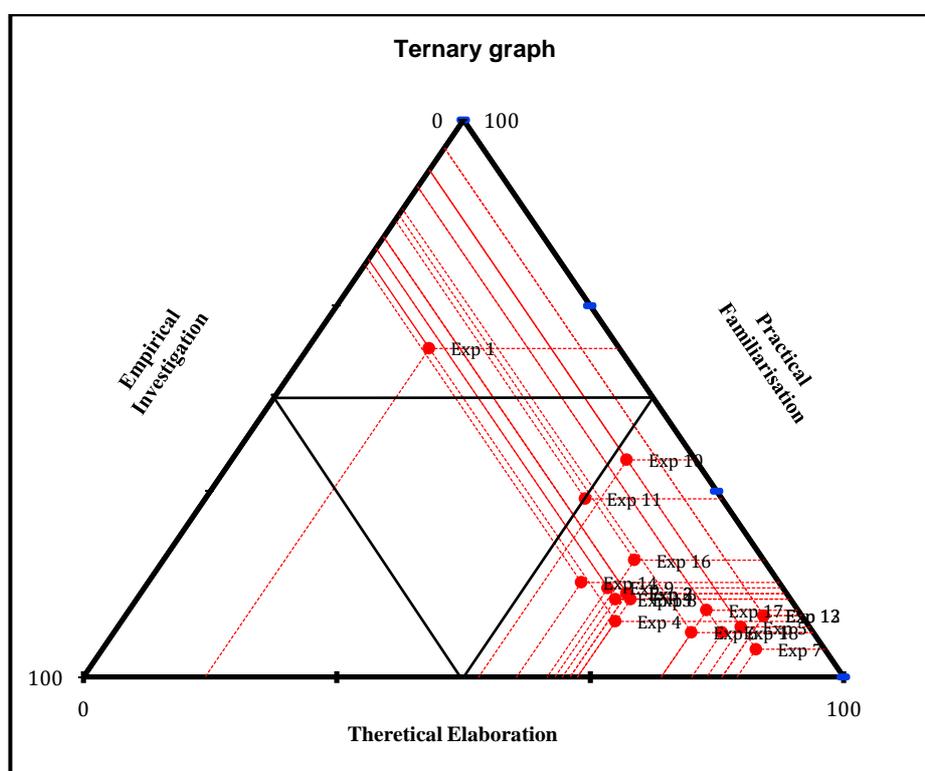


Figure 1: Ternary graph of the three didactics modes of the scientific experiment

Discussion

From the ternary graph (Figure 1), it can be observed that all the experiments, except one, fall within the theoretical elaboration triangle, although some are close to the area of uncertainty (the centre triangle). Only one experiment falls within the practical familiarisation triangle, whereas the empirical investigation triangle is completely empty.

From these observations, it can be deduced that the three didactic modes of scientific experiments are not programmed in a logical and balanced way in Moroccan textbooks. Indeed, the textbook authors tend to assign more importance, in terms of the number of programmed experiments, to experiments aimed at constructing concepts (theoretical elaboration mode) at the expense of empirical investigation experiments and practical familiarisation experiments. The latter two, although included in the teaching/learning process, are not used frequently and rarely intentionally scheduled.

Besides, teachers are highly focused on completing the course on time, which primarily uses the experimental concept-building function, leaving little time for practical familiarisation experiments as well as those aimed at acquiring experimental reasoning methodology. Moreover, even when the textbook authors and teachers do include such

experiments, it is mainly to serve the function of theoretical elaboration. And yet, it is interesting to note that the official instructions (Official program, 2007) insists on including the three didactic modes in science textbooks.

Furthermore, the fact that one didactic mode (theoretical elaboration) is favoured to the detriment of the other two (practical familiarisation and empirical investigation) raises the question of congruence between the curriculum and the official instructions. It also suggests that the official instructions are not properly operationalised during the process of preparing the content of the curriculum. Moreover, the graphical representation of the experiments in the triangular diagram shows that no experiment is positioned on one of the vertices of the triangle, which means that all the experiments are composites of the three didactic modes.

Despite this focus on the concepts' installation through textbook experiments, the problem of misconceptions regarding photosynthesis is an obstacle to the concepts' appropriation by learners (Metioui et al., 2016; Svandova, 2014). Several research projects are investigating new teaching approaches aimed at correcting and thus overcoming these misconceptions. Among the approaches that have proved effective are the investigative approach (O'Connell, 2008), concept modelling (Ross et al., 2006), inquiry-based teaching (Nas, 2010), the conceptual change model (Tlala et al., 2014), the PPDP** strategy (Ulfa et al., 2017) and the use of computer-assisted teaching materials (Keles & Kefeli, 2010).

Conclusions

In order to determine the didactic modes within the Moroccan high school science curriculum, the experiments of a chapter of the 1st year baccalaureate textbook were selected and then subjected to an analysis by using appropriate grids.

The chapter "photosynthesis" was selected as the object of study, firstly because it is a complex field (Johnstone & Mahmood, 1980; Finley and al., 1982), secondly, its mastery requires an understanding of multiple facts, relations and concepts (Selmaoui & Aznadi, 2011) and finally because the learner represents insufficient cognitive structures on this concept (Kurt et al., 2013).

The photosynthesis chapter in an official edition of the textbook allowed the selection of 18 experiments.

Using analytical grids derived from Coquide and Astolfi's work, the 18 experiments present within the photosynthesis chapter were analysed.

The analysis showed that among these investigated experiments, none belonged to the empirical investigation mode; only one belonged to the practical familiarization mode while the rest belonged to the theoretical elaboration mode.

This suggests that the content of the experimental scientific program focuses on the theoretical development mode at the expense of other modes of empirical investigation and practical familiarization. Similar studies within the french educational science curriculum showed the same trend in terms of focus on the theoretical development mode (Coquide, 2003).

Finally, the textbook is an essential science teaching and learning component and its usage has an important influence on pedagogical practices, course contents and experimental teaching processes (Selmaoui et al., 2017). Therefore, it is imperative to strenghten the presence of all the three didactic modes (theoretical elaboration, practical familiarisation and empirical investigation) within the textbook content. This will allow the construction of concepts, empirical referents and scientific attitudes, the development of reflective thinking and experimental methodology among learners ; which will lead to a generation able to master various skills, able to reason scientifically and able to resolve problems.

Suggestions

It would be useful to expand the study to cover the entire science curriculum in order to strengthen the reliability of its conclusions. Furthermore, there is a need for future studies to strengthen the processes of didactics and pedagogical rationalisation. Finally, the model and its implications must find a prominent place in teacher-education programs, textbooks, and classroom practice.

To implement practical actions aimed at improving experimental skills, students must first be aware of the importance of these experimental skills and be motivated to develop those (Maskour et al., 2019). Furthermore, activities such as laboratory experiments can be effective methods for teaching difficult concepts such as photosynthesis (Iancu & Chilom, 2016).

Besides, diversity in the teaching materials used in science courses is an indicator of effective learning (El Batri et al., 2019). A considerable interest must be paid to experimental and new pedagogical approaches for teaching complex phenomena such as photosynthesis (Iancu & Chilom, 2016).

** Personal and Professional Development Planning

Finally, the use of ICT in experiments is recommended in order to explain certain complex science topics. Nevertheless, the use of ICT in science teaching remains limited, and the factors that most hinder its integration into the teaching process have been shown in previous studies (Nafidi et al., 2018; Benfares et al., 2015).

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