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The Influence of Environmental Factors on Photosynthesis - Learning Design and Assessment Plan for a STEM Curriculum

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Abstract. There has been a lot of attention on STEM education, but there is less STEM curriculum for teachers to have a reference point in China. The article proposes a short STEM curriculum for use by teachers in the teaching of the STEM curriculum. The curriculum is for 10th graders. Biology is the main subject integrated with mathematics and chemistry. The article shows specific course content, including 3 different experiments. Experiments in which students participate independently are more likely to sharpen their thinking. Inquiry-based learning is adopted as the educational approach, through which students can discover new causal relationships because students formulate hypotheses and test them by conducting experiments and observations. Additionally inquiry-based learning encourages students to think logically, critically, and analytically, which is helpful in increasing students' critical thinking. Critical thinking is reasonable and reflective thinking focused on what to believe or do. Students with critical thinking skills can achieve incredible learning outcomes because they can consciously control their goals and attention. There are six dimensions of critical thinking, based on the assignment—experimental report, analysis dimension and explanation dimension will be assessed.

Keywords. STEM curriculum, high school, learning design, inquiry-based learning, learning assessment

1. Introduction of curriculum

Topic: The Influence of Environmental Factors on Photosynthesis

Level of students: Grade 10

Subjects involved: Biology, Mathematics, Chemistry

Number of lessons: 3 lessons with 40 minutes for each in the classroom

Prerequisites of the curriculum:

Students need to know the basic knowledge of photosynthesis, like the approximate process of photosynthesis and the raw materials and products of photosynthesis;

Students need to know the basic principles of experimental design and know how to perform quantitative experiments;

Students need to have a certain mathematical foundation, like understanding how to generate math curves with Excel and analyze curve data;

Students need to know the principle of the color change of the Bromothymol Blue indicator.

Learning outcomes of the curriculum:
1. Identify how the environmental factors influence photosynthesis under some conditions.
2. Process and analyze the raw experimental data preliminarily.
3. Explain own arguments and corresponding reasons clearly supported by the experimental data.
4. Construct mathematical models of the effects of light intensity and temperature on photosynthesis.

2. Theoretical Framework

2.1 Critical thinking

Twenty-first-century competencies can support individual's deeper learning and knowledge transfer, including cognitive, interpersonal, and intrapersonal characteristics (Honey et al., 2014). Critical thinking, one cognitive characteristic of 21st-century competencies, is essential in today and future competitions. Critical thinking is reasonable and reflective thinking focused on what to believe or do (Ennis, 2016). For example, a person has to give reasons for the argument he believes when reasoning, which needs and exercises his critical thinking skill (Mulnix, 2012). Students with critical thinking skills can achieve incredible learning outcomes because they can consciously control their goals and attention (Kamal & Suyanta, 2021). In addition, students' critical thinking skills are exercised when learners use critical thinking skills to understand knowledge and solve the problems they face (Rahmi et al., 2019).

Facione (2011) proposed six dimensions of critical thinking: interpretation, analysis, inference, evaluation, explanation, and self-regulation. In this curriculum, learning outcomes are designed based on the analysis dimension and explanation dimension of critical thinking. Thus, these two dimensions are introduced below. Analysis refers to identifying the intended relationships among statements, questions, concepts, descriptions, including examining ideas, identifying arguments, reasons and claims. Explanation refers to presenting, stating, and justifying the reasoning based on the experimental results.

2.2 Inquiry-based learning

Keselman's (2003) definition of inquiry-based learning is adopted: Inquiry-based learning is an educational strategy in which students construct knowledge through following methods and practices similar to those of professional scientists. Additionally, students can discover new causal relationships through inquiry-based learning because students formulate hypotheses and test them by conducting experiments and/or observations in the process of inquiry-based learning (Pedaste et al., 2012). Inquiry-based learning begins with an essential question,

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emphasizing the process of scientific discovery. In science education, inquiry-based learning encourages students to think logically, critically, and analytically and produce superior learning outcomes (Rahmi et al., 2019). Also, the inquiry-based learning approach is helpful in increasing students' critical thinking skills (Kamal et al., 2021)

According to Pedaste (2015), there are five inquiry phases for complete inquiry-based learning, as shown in Figure. 1.

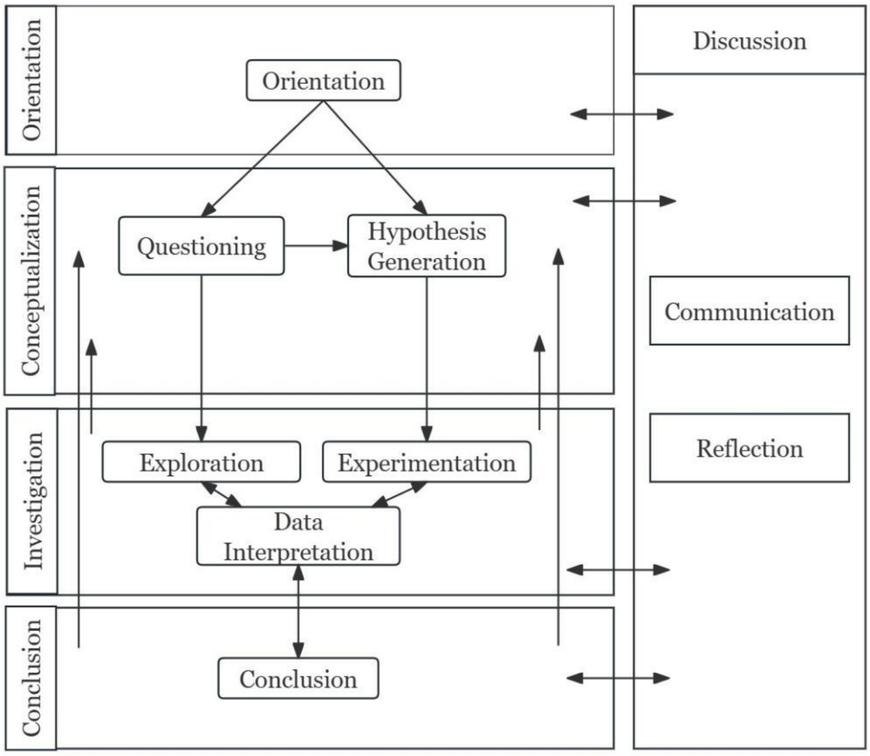

Figure.1. The inquiry-based learning framework (Pedaste et al., 2015)

Orientation refers to arousing students' curiosity and interest about a topic. In addition, the learning topic is given by the teacher, or introduced by the environment in this stage.

Conceptualization refers to that students understand concepts that belong to the stated problem, involving two sub-phases: questioning (generating questions) and hypothesis generation (generating hypothesis).

Investigation refers to that students design different experiments by changing variable values, and interpret data, involving three sub-phases: exploration, experimentation (designing and conducting an experiment to test a hypothesis), and data interpretation.

Conclusion: Students draw conclusions from the experimental results and compare inferences with hypotheses.

Discussion involves two sub-phases: communication (presenting outcomes to peers and teachers to get feedback from them) and reflection (discussing the whole inquiry cycle). The discussion phase is optional during these five phases because learners can obtain learning outcomes without communication and reflection (Pedaste et al., 2015).

Moreover Pedaste (2015) proposed three paths of the approach: data-driven approach, hypothesis-driven approach, and question-driven approach. In this curriculum, the question-driven approach is chosen, involving orientation, questioning, hypothesis generation, experimentation, data interpretation, and conclusion.

2.3 Discipline-based model

This curriculum adopts the discipline-focused model in various integrated STEM education models. Discipline-focused model is that a particular dominant discipline forms the center of a learning task, which is integrated with one or more other disciplines while using or reinforcing representative knowledge and skills from this discipline, to solve real-world problems (Kysilka, 1998; Honey et al., 2014; Fan et al., 2020).

According to Yildirim (2017), there are five iterative procedures in a discipline-focused model: 1) Identifying the main subject to integrate disciplines. Biology is the main subject in the curriculum to integrate other disciplines; 2) Identifying the learning domains. Photosynthesis is an important life activity of green plants. Relevant knowledge is the crucial point in Compulsory-One, and it is also the critical point in the high school biological knowledge system. Thus, the topic of the curriculum is——The influence of environmental factors on photosynthesis; 3) Identifying the integration between the subjects. In the experiment, the BTB indicator will be used, and simple mathematical modeling will be used to describe the experimental data clearly; 4) Designing the activity. The activities are designed based on the inquiry-based learning framework and the discipline-focused model; 5) Applying the activity and evaluating it.

3. Implementation——Outline of the major learning activities

The designed learning activities are referred to the inquiry-based learning framework and discipline-based model above. Major learning activities can be seen in table1.

Table 1. Outline of the major learning activities

Learning activity	Introduction	Materials
Introducing principles and applications of photosynthesis and the learning topic of the curriculum	This is the orientation and conceptualization stage. In the beginning, the teacher will introduce some applications of photosynthesis to arouse students' interest. Then the teacher will introduce the principles and complete process of photosynthesis. Furthermore, the teacher helps the students clarify the difference between the dependent variables and independent variables. Additionally, the teacher will introduce the learning	Slides and videos about the applications of photosynthesis

	topic——The influence of environmental factors on photosynthesis. Students will generate questions about which environmental factors could influence photosynthesis and generate hypothesis based on the questions. Tip: Students can choose one or more of the plants to conduct experiments based on the plants provided by the teacher.	
Experiment1—The effect of light intensity on photosynthesis	This is the investigation stage (experimentation) and discussion stage. With or without the teacher's help (depending on the students' experimental-design abilities), two students work as a group to design Experiment1 by changing light intensity variable values and making a hypothesis, then conduct the experiment to test the hypothesis. Students need to record experimental data in the Experimental result data record form and fill in experimental data into the computer Excel form to generate the mathematical model curve to draw preliminary conclusions about how light intensity influences photosynthesis. Also, during the experiment, students are highly encouraged to communicate with peers and teachers	Basic facilities of a biological laboratory; Lab computer; Bromothymol Blue indicator; 2%$NaHCO_3$ concentration; WIFI smart bulbs; Plants (Spinach leaves, Chlorophytum leaves, Houttuynia cordata leaves, Pedilanthus tithymaloides leaves, Gynura cusimbua leaves); Thermostatic heating device; The sample of experimental result data record form (see Appendix One)

	about the experimental design and experimental data.	
Experiment2—The effect of light quality on photosynthesis	This is the investigation stage (experimentation) and discussion stage. With or without the teacher's help (depending on the students' experimental-design abilities), two students work as a group to design Experiment2 by changing light quality variable values and making a hypothesis, then conduct the experiment to test the hypothesis. Students need to record experimental data in the Experimental result data record form and fill in experimental data into the computer Excel form to generate the mathematical model curve to draw preliminary conclusions about how light quality influences photosynthesis. Also, during the experiment, students are highly encouraged to communicate with peers and teachers about the experimental design and experimental data.	Basic facilities of a biological laboratory; Lab computer; Bromothymol Blue indicator; 2%$NaHCO_3$ concentration; WIFI smart bulbs; Plants (Spinach leaves, Chlorophytum leaves, Houttuynia cordata leaves, Pedilanthus tithymaloides leaves, Gynura cusimbua leaves); Thermostatic heating device; The sample of experimental result data record form (see Appendix One)
Experiment3—The effect of light intensity — temperature on photosynthesis	This is the investigation stage (experimentation) and discussion stage. This experiment is a two-factor experiment, so it is more demanding for students.	Basic facilities of a biological laboratory; Lab computer; Bromothymol Blue indicator; 2%$NaHCO_3$ concentration; WIFI smart bulbs;

	The teacher can instruct students in advance to conduct a 2-factor pre-experiment so that students can know how to design a 2-factor experiment. Then two students work as a group to design Experiment3 by changing the groups of light intensity —temperature and making hypothesis, then conduct the experiment to test the hypothesis. Students need to record experimental data in the Experimental result data record form and fill in experimental data into the computer Excel form to generate the mathematical model curve to draw preliminary conclusions about how light quality influences photosynthesis. Also, during the experiment, students are highly encouraged to communicate with peers and teachers about the experimental design and experimental data.	Plants (Spinach leaves, Chlorophytum leaves, Houttuynia cordata leaves, Pedilanthus tithymaloides leaves, Gynura cusimbua leaves); Thermostatic heating device; The sample of experimental result data record form (see Appendix One)
Additional task (Optional for students)	After completing these three experiments, students are encouraged to conduct additional but more complex experiments. These tasks are optional, so students can choose to do or not to do them. Task 1: To investigate the effect of CO_2 concentration on photosynthesis	Basic facilities of a biological laboratory; Lab computer; Bromothymol Blue indicator; 2%$NaHCO_3$ concentration; WIFI smart bulbs; Plants (Spinach leaves, Chlorophytum leaves, Houttuynia cordata leaves, Pedilanthus

	Task 2: To investigate the optimum light quality for different plants Task 3: To investigate the optimum light intensity-temperature for different plants	tithymaloides leaves, Gynura cusimbua leaves); Thermostatic heating device;
Writing experimental reports	This is the investigation (data interpretation), conclusion and discussion stage. After completing all experiments, students will discuss all the results with peers and teachers. In addition, students are required to accomplish individual experimental reports based on the process and data of the experiments in a week. Students need to accomplish data interpretation and draw final conclusions about each experiment in the experimental report. The teacher needs to introduce the required parts of the experimental report: Introduction, Hypothesis, Experimental design and procedure, Data collection and analysis, Conclusion, Components of the report, Spelling-Punctuation-Grammar (Knaggs et al., 2012)	Slides about the required parts of the experimental report

4. Assessment

4.1 Assessment of students' individual experimental reports

Students are required to complete individual experimental reports within one week after the experiments are completed. Students' standardized writing of experimental report forms is beneficial for students (Ding, 2016), like improving students' basic experimental skills, problem-solving skills, and critical thinking skills, and helping students consolidate knowledge. In addition, the data analysis and conclusion of the experimental report will show the analysis dimension and explanation dimension of students' critical thinking. Moreover, the experimental report will show the students' in-class participation, as students can only get actual experimental data by conducting experiments.

Therefore, the experimental report is the assignment of this curriculum for students. Furthermore, the teacher will mark students' individual experimental reports based on the rubric shown in Appendix Two. This rubric is designed with reference to Knaggs et al. (2012).

4.2 Assessment of student's analysis and explanation dimension of critical thinking skills—— Online California Critical Thinking Skills Test (CCTST)

The California Critical Thinking Skills Test (CCTST) is developed based on the critical thinking theory developed by the American Psychological Association in 1990 (Luo & Yang, 2002). In this theory, critical thinking skills conclude six dimensions: interpretation, analysis, inference, evaluation, explanation, and self-regulation, the same as Facione's argument of six dimensions of critical thinking (2015).

There are around 40 engaging and scenario-based questions in the CCTST. After accomplishing the online CCTST, students will get a report, including an overall score of critical thinking skills (a 100-point scale) and scores for each dimension (analysis, interpretation, inference, evaluation, explanation, induction, deduction, and numeracy). And every score is on a 100-point scale. This professional report gives detailed information on the level of critical thinking skills of each student, the level of each dimension of the critical thinking skills, and the average level of all students' critical thinking. The teacher can see scores of analysis and explanation in the report to further assess student's analysis and explanation dimension of critical thinking.

5. Anticipated challenges ahead and the potential solutions

When implementing the curriculum, there may be some challenges. Table 2 shows some anticipated challenges and corresponding potential solutions.

Table 2. Anticipated challenges and potential solutions

Anticipated challenges	Potential solutions
Some teachers may have no idea about how to implement inquiry-based learning STEM activities in class, so they may not be able to implement the curriculum as expected.	Developing in-service training for teachers. In-service training should focus on providing practice and application rather than information. In addition, teachers should be tracked to see how they apply what they have learned from in-service training in the classroom, and the findings should be evaluated together (Duran & Dökme, 2016).

Some teachers may have difficulty accurately determining students' learning needs and assessing students' learning (Cheng & Lee, 2010).	Developing clear rubrics and using rubrics as a guide for learning and instruction (Cheng & Lee, 2010). With rubrics, teachers could know clearly what knowledge and skills they could teach and assess and might assess student performance frequently in small and focused tasks. Thus, teachers are more likely to diagnose the students' strengths and weaknesses accurately and precisely.
Some students may lack background knowledge, so they have difficulty in designing experiments and interpreting data (Edelson et al., 1999).	Providing embedded information sources, like the school library and online learning platforms (Edelson et al., 1999) for students. Students can obtain information in time through embedded information sources to complete the experiments.
Some students may not master scientific techniques (like data collection and analysis) and instruments required for the experiment (Edelson et al., 1999).	Providing bridging activities (Edelson et al., 1999) for students. Students can be familiar with scientific practices through bridging activities, as bridging activities use practices that students are familiar with to introduce unfamiliar scientific practices.

References:

Cheng, M., & Lee, T. (2010). Addressing the challenges in school-based assessment : Practices in the assessment of inquiry learning. *Curriculum and Teaching, 25*(1), 25-41.

Ding Shaohui.(2016).论实验报告单的重要性. *新课程*(下)(11),218.

Duran, M., & Dökme, I. (2016). The effect of the inquiry-based learning approach on student's critical-thinking skills. *Eurasia Journal of Mathematics Science and Technology Education, 12*(12).

Edelson, D., Gordin, D., & Pea, R. (1999). Addressing the Challenges of Inquiry-Based Learning Through Technology and Curriculum Design. *The Journal of the Learning Sciences, 8*(3-4), 391-450.

Ennis, R. (2016). Critical Thinking Across the Curriculum: A Vision. *Topoi, 37*(1), 165-184.

Facione, P. A. (2011). Critical thinking: What it is and why it counts. *Insight assessment, 2007*(1), 1-23.

Fan, S., Yu, K., & Lin, K. (2020). A Framework for Implementing an Engineering-Focused STEM Curriculum. *International Journal of Science and Mathematics Education, 19*(8), 1523-1541.

Honey, M., Pearson, G., & Schweingruber, H. (Eds.). (2014). *STEM integration in K-12 education: Status, prospects, and an agenda for research*. Washington, D.C.: National Academies Press.

Kamal, N., & Suyanta. (2021). The effect of inquiry based learning models on students' critical thinking ability and self-efficacy in reaction rate material. *Journal of Physics. Conference Series, 1806*(1), 12179.

Keselman, A. (2003). Supporting inquiry learning by promoting normative understanding of multivariable causality. *Journal of Research in Science Teaching, 40*(9), 898-921.

Knaggs, C. M., & Schneider, R. M. (2012). Thinking like a scientist: Using vee-maps to understand process and concepts in science. *Research in Science Education, 42*(4), 609-632.

Kysilka, M. (1998). Understanding integrated curriculum. *Curriculum Journal (London, England), 9*(2), 197-209.

Luo Qingxu,& Yang Xinhui.(2002).《加利福尼亚批判性思维技能测验》的初步修订. *心理科学*(06),740-741.

Mulnix, J. (2012). Thinking Critically about Critical Thinking. *Educational Philosophy and Theory, 44*(5), 464-479.

Pedaste, M., Mäeots, M., Leijen, Ä., & Sarapuu, S. (2012). Improving students' inquiry skills through reflection and self-regulation scaffolds. *Technology, Instruction, Cognition and Learning, 9*(1-2), 81-95.

Pedaste, M., Mäeots, M., Siiman, L. A., De Jong, T., Van Riesen, S. A., Kamp, E. T., ... & Tsourlidaki, E. (2015). Phases of inquiry-based learning: Definitions and the inquiry cycle. *Educational research review, 14*, 47-61.

Rahmi, Y., Alberida, H., & Astuti, M. (2019). Enhancing students' critical thinking skills through inquiry-based learning model. *Journal of Physics. Conference Series, 1317*(1), 12193.

Yildirim, B., & Selvi, M. (2017). An experimental research on effects of STEM applications and mastery learning. *Journal of Theory and Practice in Education, 13*(2), 183-210.

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Appendix One: Experimental result data record form sample

Experiment1 The effect of light intensity on photosynthesis
Type of plants:

Experimental Group	Experimental Conditions			Number of floating leaves in 5 minutes
	Temperature	CO_2%	light intensity	
1	24℃	2%$NaHCO_3$	500lx	
2	24℃	2%$NaHCO_3$	1000lx	
3	24℃	2%$NaHCO_3$	1500lx	
4	24℃	2%$NaHCO_3$	2000lx	

Experiment2 The effect of light quality on photosynthesis
Type of plants:

Experimental Group	Experimental Conditions				Number of floating leaves in 5 minutes
	Temperature	CO_2%	light quality	light intensity	
1	25℃	2%$NaHCO_3$	Red light	1000lx	
2	25℃	2%$NaHCO_3$	Orange light	1000lx	
3	25℃	2%$NaHCO_3$	Yellow light	1000lx	
4	25℃	2%$NaHCO_3$	Green light	1000lx	
5	25℃	2%$NaHCO_3$	Blue light	1000lx	
6	25℃	2%$NaHCO_3$	Violet light	1000lx	
7	25℃	2%$NaHCO_3$	White light	1000lx	

Experiment3 The effect of temperature-light intensity on photosynthesis

CO_2%:
Light quality:
Temperature:
Type of plants:

	500lx	1000lx	1500lx	2000lx
20℃	(Number of floating leaves in 5 minutes)			
25℃				
30℃				
35℃				

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Appendix Two

Rubric for assessing students' individual experimental reports

Score / Category	4	3	2	1
Introduction	The purpose of the experiment and the studied variables are clearly stated in the introduction.	The purpose of the experiment and the studied variables are stated, but not clearly.	The purpose of the experiment is stated but the introduction of variables is missing.	There is no introduction.
Hypothesis	Hypothesis is clear and reasonable based on general knowledge and observations.	Hypothesis is reasonable based on general knowledge and observations, but not clear enough.	Hypothesis is stated but the logic supporting the hypothesis is flawed.	There is no hypothesis.
Experimental Design and Procedure	The designed experiment is well-constructed to test the hypothesis. Variables and controls are properly identified. The description of experiment is clear, and procedures are listed in a logical order.	The designed experiment is adequate to test the hypothesis but has some unanswered questions. Variables and controls are properly identified. The description of the experiment is inaccurate and some procedures are not clearly explained.	The designed experiment can test the hypothesis but is not complete enough. Variables or controls may not be identified properly. The description is incomplete and some steps are missing.	The designed experiment can't test the hypothesis. Variables and controls are not identified properly, or they are absent. The description of the experiment is incomplete and some key steps are missing.
Data collection and analysis	All the experimental data obtained is included. Key results are	Less than two key results are missing.	More than two key results are missing.	Major results are not included.

	present in a logical order. Tables and figures are present properly.	Figures and tables are present but contain minor errors.	Figures lack proper identification. Tables have missing titles. The order of text is not logical.	Figures and tables are poorly constructed or not present. There is evidence of plagiarism.
Conclusion	Interpretation of results is proper. Connections between conclusions and scientific concepts are clear and references are reviewed. There are discussions about applications or real-life situations.	Interpretation of results is presented. Connections between conclusions and scientific concepts are clear. However, there is a lack of literature.	Interpretation of key results is poor. Connections between conclusions and scientific concepts are present, but not clear enough.	Interpretatio n of the results is missing. Connections between conclusions and concepts are lacking or incorrect.
Report format	All required elements are present and additional elements (like thoughtful comments, additional-advanced experimental data) are added.	All required elements are present.	One required element is missing, but additional elements (like thoughtful comments and graphics) are added.	Several required elements are missing.
Spelling and Grammar	Three or fewer errors in spelling and grammar in the report.	Four to seven errors in spelling and grammar in the report.	Seven to ten errors in spelling and grammar in the report.	More than ten errors in spelling and grammar in the report.

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STUDENT NAME: ***TOTAL POINTS ________/ 28***
COMMENTS: ____ ____ ____ ____ ____ ____ ____