A Summative Assessment Approach for a Photosynthesis Module (Revised)

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Cover Letter

I selected a model from NetLogo, “Chloroplasts and Food”, because of the fact that plants play a dominant role in maintaining balance in our ecosystem. Understanding the requirements plants have for sustaining their own existence bears directly on their ability to provide that balance, as well as for their ability to reproduce and flourish. In our present-day global systems approach, destruction of plant life in favor of economic growth and human population expansion is a trend that, while reversible, impacts nearly every form of life on the planet. Therefore, students should understand how and why plants survive, how they produce energy, generate by-products such as oxygen that sustain other forms of life – as well as the consequences for diminishing their numbers and their efficacy.

Central to my approach was to sharpen the emphasis on developing and observing emergent thinking in students, based upon the writings of Jacobson and Wilensky. I did so by emphasizing the student’s leveraging their learnings of the structure and function of plant cells, and using NetLogo to motivate experimentation into the factors that influence the production of glucose, which provides the energy source for plant sustenance and reproduction. In this way, the students should develop a conceptual framework to “connect the dots” from the elements of plant structure to the complexity of a living organism.

To support the summative assessment, I aligned the Understanding by Design of Wiggins & McTighe to the assessment model taken from the book edited by Marion & Pelligrino, focusing upon the evaluation of student cognition, the observation of student capabilities, and the interpretation of outcomes. The fourth element of this framework, validity, was a greater challenge than I could initially address in the first version of this paper.

I also included more challenging criteria to assess student understanding and mastery of the concepts. Clearly, we expect our students to explain the structure, function, and mechanisms that comprise photosynthesis. However, we also should expect them to form hypotheses and make predictions about the impacts that the environment makes upon a plants' ability to produce glucose. I developed a set of challenges for students to inquire on the effects of changing the degree sunlight and water absorption have on glucose production, as well as to predict what happens to a plant when too much (or not enough) glucose is produced, and why the plant responds under those conditions. I aligned these challenges to Bloom's taxonomy, so that cognitive capabilities from the elementary (remembering, understanding, and applying) to the more sophisticated (analyzing, evaluating, and creating) could be measured by formulating test questions commensurate to those capabilities.

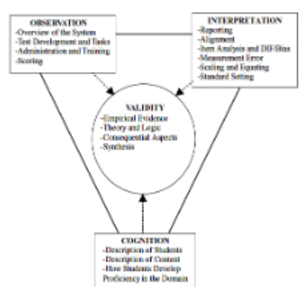
Finally, I researched the nature of validity, and discovered from an article by Kibble, a set of criteria that prescribes activities both in curriculum planning and assessment development. When followed, these provide more confidence in the validity of the assessment instruments, which I believe is important given its importance in the assessment triangle model. I think that this new information puts the paper on solid conceptual footing and (hopefully) improves its coherence and readability.

Approaches to Assessment in Systems Learning

The learning sciences have emphasized the evaluation of systems thinking in the context of scientific disciplines. I selected an approach that emphasizes the validity of assessments along with their reliability, using a “triangle model” that defines the relationship among cognition (student learning in the domain), observation (evidence of student competencies), and interpretation (a framework to assemble and give context to the evidence) (Marion & Pellegrino, 2007). This approach was augmented to incorporate definitive relationships these three areas to the concept of validity, as shown in the diagram below.

Figure 1

Overlaying the assessment triangle and topics from technical documents.



From Marion & Pelligrino (2007), p. 52.

Assessment and Understanding by Design

Understanding by Design’s three-stage teaching approach is well-suited for both formative and summative assessments (Wiggins & McTighe, 2005). A module (comprised of five lessons) based upon NGSS HS-LS2 (Ecosystems: Interactions, Energy, and Dynamics) was presented in another paper of mine (Lesson Planning), wherein NGSS science and engineering practices, disciplinary core ideas, and cross-cutting concepts were represented. UbD provides a framework for defining goals in Stage 1, specifying assessment evidence in Stage 2, and supporting the "explore-before-explain" instructional sequence in Stage 3. In this way, the NGSS call for learners to be "doing" science is honored (McTighe & Brown, 2021).

Implementation of Summative Assessment

A summative assessment is a tool that helps determine if a student has attained mastery after completing a certain phase of education – in this case, a photosynthesis module in a high school biology course.

In this module, students were presented with the morphology of a plant cell, along with the functions within that structure. Using NetLogo, they examined the mathematical and computational relationships that comprise the mechanism of Photosynthesis. This approach is fundamentally constructivist, as working with models gives students a chance to articulate, evaluate, and refine their thinking, since NetLogo accurately simulates the emergence of observable phenomena at the aggregate level. (Swanson & Wilensky, 2024). Observing the structure to function to mechanism was expected to equip students to perform adequately on a summative assessment of their understanding of photosynthesis.

In order to correctly implement a summative assessment, the principles of the assessment triangle are invoked. To do so, leading practices for summative assessment were researched, and in particular, the properties of test validity were evaluated. These practices clearly informed the type, depth, and breadth of the questions that were proposed in the Observation aspect of the triangle model, but more importantly, were essential in formulating the curriculum and lesson plans in the Cognitive aspect.

Cognition

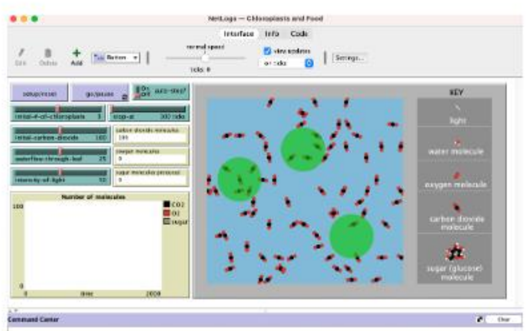
Following the "triangle" assessment method, and the principles of leading practice for summative assessment, the UbD framework described above was employed, due to its "backward design" philosophy. The "targets of inference" for this assessment would involve a combination of the student's ability to identify the structure of the chloroplast, and specify the functions performed by each component of the cell, to both explain and predict the mechanism and outputs of photosynthesis based upon changes in inputs.

To facilitate understanding, each student will use NetLogo to examine the mathematical and computational relationships that comprise the mechanism of Photosynthesis. This computational modeling approach is fundamentally constructivist, as building and operating models gives students a chance to articulate, evaluate, and refine emergent thinking from molecular to organism levels (Swanson & Wilensky, 2024).

The diagram below depicts the initial state of the NetLogo model.

Figure 2

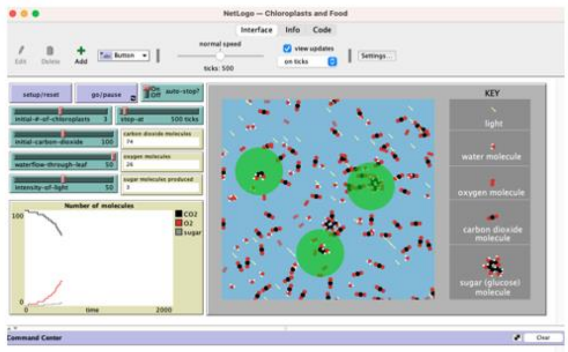
Illustration of NetLogo model "Chloroplasts and Food" set to initial conditions. Note that default values for chloroplast counts and CO_2 counts are fixed, and O_2, and glucose molecules are set to zero



Now the student increases the waterflow to 50.

Figure 3

Illustration of NetLogo model "Chloroplasts and Food" set to maximum waterflow. This doubled the number of O_2 molecules (as expected), but dramatically increased the glucose production as well.



Thus, based upon the knowledge gained from a didactic presentation of plant cell structure and function, as well as simulations using NetLogo, the student is expected to demonstrate a capacity for emergent thinking by describing the mechanism by which photosynthesis performs nominally, the conditions necessary for its increased (or interrupted) production of glucose, the process of transforming glucose into starch (polymerization, creating two polysaccharides, amylose and amylopectin), and the reasons why glucose production is essential to the plant itself. In addition, the student should demonstrate their understanding of "boundary conditions" (e.g., the limitations of water absorption (number and capacity of stoma), the impact of glucose production beyond the immediate energy needs of the plant (transformed to starch and stored throughout the structure of the plant), and the effect of exceeding the upper limit of starch storage capacity (reverse osmosis occurs, causing water loss and ultimately death).

Observation

Both the AAAS Vision and Change report (AAAS, 2023), as well as the NGSS charter (NGSS, 2013), prioritize “big-picture learning outcomes” in course planning as well as in measuring learning outcomes Learning taxonomies are helpful when developing and matching learning outcomes with assessments (Kibble, 2017). In an effort to do so, I used Bloom’s taxonomy (Bloom et al., 1964), along with its modifications by Anderson and Krathwohl (2001) to obtain six cognitive process dimensions (remembering, understanding, applying, analyzing, evaluating, and creating). For this paper, a small number of questions will illustrate how such a sample could be constructed. A table reflecting this taxonomy, and its application to the summative assessments in this paper, is shown below.

Figure 4

Alignment of summative examination questions to taxonomy proposed by Bloom, et al. (1965) and Anderson and Krathwohl (2001)

Targets of Inference / **Cognitive Level**	Plant Anatomy	Reactants and Products	Structures and Processes	Relevance and Context
Remembering	2	11	1, 7	1
Understanding	5	3, 8, 11	4, 7	2,3,4
Applying	2, 5	6, 8, 11	5, 7	9
Analyzing	5	3, 6, 7, 8	4, 5, 6	9
Evaluating	4	6, 7, 8	4, 7	9
Creating		8, 10	10	10

Note: numerals refer to test questions listed below.

Based upon the NGSS-inspired lesson plan, as well as the taxonomy above, sample questions are provided in the table below:

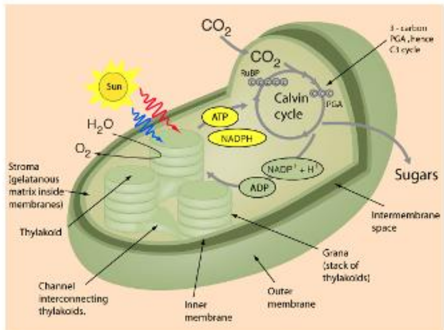
Figure 5

Sample questions for a summative assessment of a photosynthesis module in high school biology.

#	Question	Response Type	Answer
1	Explain the overall purpose of photosynthesis on a macro level, relating to the organism in its entirety.	Short answer	To furnish the plant with glucose, an energy source to fuel its cellular function, and to sustain its life and reproductive capability.
2	Identify the key functions of the chloroplast responsible for photosynthesis.	Complete Figure 6	Chloroplasts, a specialized intracellular organelle, perform photosynthesis using light. The immediate products of photosynthesis, NADPH and ATP, are used by the photosynthetic cells to produce many organic molecules.
3	Define and describe the phenomena of transpiration, photosynthesis and photorespiration.	Short answer.	Photosynthesis uses light energy, carbon dioxide (CO_2), and water (H_2O) to produce glucose and oxygen. Chlorophyll captures the light energy and converts it into energy stored in sugars. Transpiration is important for cooling the plant, acquiring CO_2, maintaining plant turgor, and absorbing mineral nutrients, since water vapor is lost through the stomata, or pores, on the undersides of leaves. Plants use metabolized sugars to produce energy for growth, reproduction, and other life processes. Respiration uses glucose and oxygen to generate kinetic energy, with carbon dioxide and water as byproducts.
4	Describe the Calvin Cycle, including its main inputs, processes, and outputs.	Short answer, complete Figure 7.	The Calvin cycle, also known as the light-independent reactions, is a series of chemical reactions that occur in the second stage of photosynthesis. The cycle takes place in the stroma, the fluid-filled region of a chloroplast, and converts carbon dioxide and hydrogen-carrier compounds into glucose. The Calvin cycle has three basic stages: Carbon fixation: Carbon dioxide enters the cycle and attaches to RuBP (ribulose bisphosphate) to produce 3-phosphoglycerate (3PG).] Energy: ATP and NADPH from the light reactions provide energy to combine the fixed carbons to make sugar Regeneration: G3P is used to remake the sugar, RuBP, and start the cycle over, or to make other molecules that can be used by the plant.
5	Describe the limitations of water absorption	Short answer.	Number and capacity of stoma in the cell.
6	The impact of glucose production beyond the immediate energy needs of the plant	Short answer.	Transformed to starch and stored throughout the structure of the plant.
7	The process of transforming glucose into starch	Short answer.	Polymerization, creating two polysaccharides, amylose and amylopectin.
8	The effect of exceeding the upper limit of starch storage capacity of the plant	Short answer.	Reverse osmosis occurs, causing water loss and ultimately death of the plant.
9	The trend of glucose production (linear or exponential)	Short answer.	Linear.
10	Explain why C4 plants evolved to decouple CO2 absorption from the Calvin Cycle and the advantage such plants have over C3 plants.	Short answer, complete Figure 8	Through the carbon fixation process.
11	Provide the chemical equation describing photosynthesis	Short answer.	$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$

Figure 6

Descriptive illustration of the structure of a typical C3 plant cell.



From Moore, et al., 1995.

Figure 7

Illustration of the Calvin Cycle (a series of chemical reactions that convert carbon dioxide and hydrogen-carrier compounds into glucose).

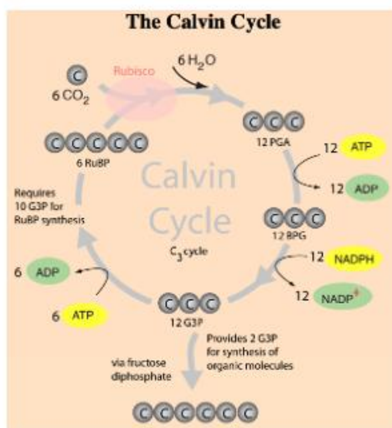
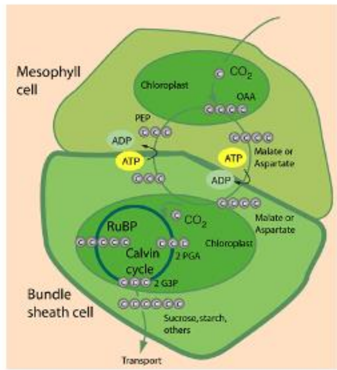


Figure 8

Illustration of the structure and nominal functions of a typical C4 plant cell, indicating the carbon-fixation process.



From Moore, et al., 1995.

Interpretation

This aspect of the assessment aims to draw inferences from the observational tasks that provide evidence of cognitive knowledge and skills. Depending upon the purpose and the audience for such results, this could range from simple descriptive statistics to a sophisticated classification-based statistical model, capable of interpreting patterns typifying different levels of student competency.

Validity

The Standards for Educational and Psychological Testing (AERA et al., 1999) provides a concise definition of validity: “Validity refers to the degree to which evidence and theory support the interpretations of test scores entailed by proposed uses of the test.” This is referred to as “construct validity”. A construct is the presumed capability of testees, that is hypothetically reflected in their test scores (Kibble, 2017).

There are leading practices for ensuring greater validity (Kibble, 2017). The table below aligns these criteria with the test questions in this paper, and thus offers a view on the degree of overall validity.

Figure 9

Criteria for summative assessment design, development, and implementation, with responses for the example in this paper (derived from Kibble, 2017).

Criteria	Implementation	Performed?
Utilize a backward design framework that declares the learning outcomes first, and then specifies the appropriate assessments to measure outcomes.	The Understanding by Design (UbD) framework was implemented, ensuring close alignment between learning outcomes, assessment measures, and value to students.	Yes
Create and socialize a testing blueprint, defining the cognitive domains to be observed, in alignment with learning outcomes.	A basic blueprint was devised based upon cognitive domain learning objectives.	Yes
Engage peer review during the test development process to avert validity bias (i.e., construct underrepresentation, construct irrelevant variance, etc.)	As this is a class exercise, peer review involved researching and citing reputable articles and applying leading practices to the selection of assessment "targets of influence".	No
Include a variety of test questions of variable difficulty, thus assuring adequate test reliability and defensibility of scores.	An effort was made to utilize Bloom's taxonomy to calibrate the cognitive skills needed to correctly respond to assessment questions.	Yes
Apply standard setting methods.	NGSS standards informed both the lesson planning and the assessment content.	Yes
Provide students with clear instructions and practice materials and develop a plan to assure the integrity of data throughout the testing process.	This would be integrated into the lesson planning. Previous test questions would be secured and not released to students.	No
Monitor the fairness, acceptability, and impact of testing over time with routine surveying of stakeholders and comparison of test scores with other measures of student outcomes.	Not applicable to this class assignment, but longitudinal analysis would typically be performed to assess fairness, acceptability, and impact.	No

The triangle model indicates that the function of validity is to assemble empirical evidence as derived from observation, theory and logic from cognition, and consequential aspects from interpretation. This synthesis should be cognizant of its uses; particularly, both validity and reliability analysis should identify potential sources of bias associated with both student level and aggregate scores, precisely because of requirements to communicate these scores to many stakeholders (Marion & Pellegrino, 2007). These sources (i.e., construct underrepresentation, construct irrelevant variance, etc.) should be addressed in the design of the assessment, and measured in a "post-mortem" analysis of the assessment.

As evidenced by the responses in Figure 9, we would expect a reasonably high degree of validity, given the relatively small number of questions.

Conclusion

I found that the triangle model emphasizing cognition, observation, and implementation fits neatly into the UbD construct for teaching and learning. I also noted that validity is largely determined by a longitudinal study of outcomes (e.g., whether passing test scores correlate with student performance at the next level). Hence, this both art and science since many statistical tools have emerged to determine reliability, but none (to my knowledge) can establish validity in advance. Perhaps this is because validity, despite the best efforts to quantify it, remains subject to interpretation of many variables which themselves are difficult to quantify, including individual characteristics of students, environmental factors, availability of resources, and other considerations.

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