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Supporting Information

The effect of the mobile learning–based PhET interactive simulation approach on students' conceptual learning and creative thinking in the concept of solutions

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Sequential Steps of Instructional Framework

The instructional framework of the ML-PhET approach was developed in accordance with the theoretical foundations of mobile learning and structured into four sequential steps. These steps aimed to enhance students' cognitive levels and creativity through interaction, exploration, and meaningful learning.

Step A- Activation: In the first step, the teacher utilized multimedia content, including images, videos, and text accessible via smartphones, to review prerequisite concepts related to solutions, such as homogeneous mixtures, solution components, and factors affecting solubility rates, thereby preparing students for the new topic.

Step B- Browsing: In the second step, students engaged in individual experimentation and exploration using the PhET interactive simulator on their smartphones. The teacher guided this process through strategic questioning, encouraging students to observe, formulate hypotheses, and test their assumptions.

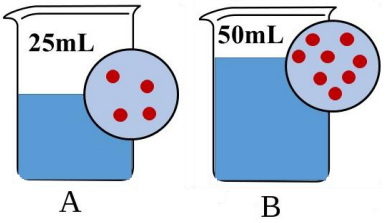
Step C- Conceptualization: In the third step, students integrated their simulation-based findings with theoretical concepts. The teacher prompted them to interpret the outcomes of their virtual experiments and present their findings in the form of graphs, explanations, or digital reports.

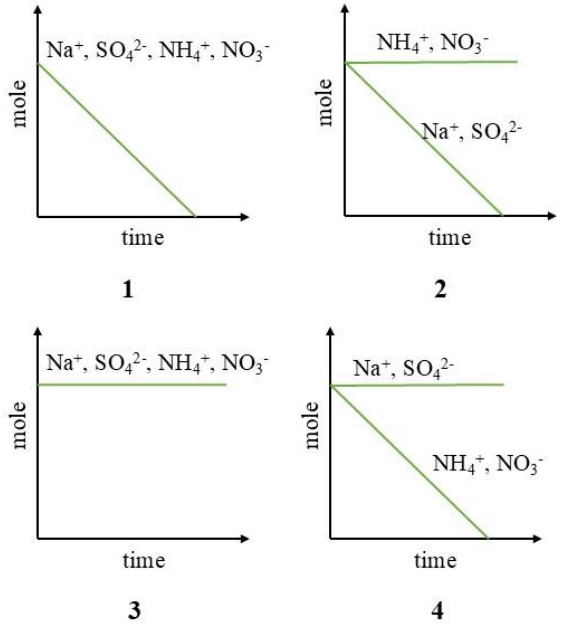
Step D- Deployment: In the fourth stage, students applied the concepts they had learned to real-world problems, thereby enhancing their problem-solving abilities, creativity, and innovation.

Research Instruments

This study utilized the mobile version of PhET interactive simulations to allow students to engage in educational activities and conduct virtual experiments in a mobile learning environment. The questions of researcher-developed academic achievement test were aligned with lesson objectives to measure the extent of their achievement. Each question was worth one point, leading to a total score range of 0 to 12, with higher scores indicating greater levels of learning. The complete learning assessment test items are provided in below.

Table S1- The learning assessment test items with cognitive domain and sub-concept of them

<table>
<tr><th>Row</th><th>Cognitive Domain</th><th>Sub-Concept</th><th>Question</th></tr>
<tr><td>Q_1</td><td>Knowledge</td><td>solution components</td><td>Define the concept of a solution and state what the substance present in the greater amount is called.</td></tr>
<tr><td>Q_2</td><td>Knowledge</td><td>solution components</td><td>If the concentration of a solution increases while its volume remains constant, how does the amount of solute change?</td></tr>
<tr><td>Q_3</td><td>Knowledge</td><td>ppm</td><td>For expressing which quantity is the unit “ppm” used, and under what circumstances is it applied?</td></tr>
<tr><td>Q_4</td><td>Comprehension</td><td>mass percent</td><td>How many grams of water must be added to 2 gr of silver nitrate to prepare a solution with a given mass percent?</td></tr>
<tr><td>Q_5</td><td>Comprehension</td><td>dilution</td><td>To prepare 500 gr of a 20% by-mass lithium chloride solution from an 80% by-mass stock solution, how many grams of the concentrated solution must be mixed with how many grams of water?</td></tr>
<tr><td>Q_6</td><td>Comprehension</td><td>molar concentration</td><td>If in each of the solutions A and B every dissolved particle is equivalent to 0.1 mol, how many times greater is the molar concentration of solution B compared to solution A?
 
</td></tr>
<tr><td>Q_7</td><td>Application</td><td>ppm</td><td>According to regulations, the amount of mercury in canned tuna should not exceed 0.2 ppm. If a 180 gr can of tuna is consumed, what is the maximum mass of mercury that may enter the body?</td></tr>
<tr><td>Q_8</td><td>Application</td><td>mass percent</td><td>Using the table below, which provides the mass of several dissolved ions in seawater, calculate the mass percent of chloride ion in seawater.
<table><tr><th>Ion</th><th>Cl^-</th><th>Na^+</th><th>SO_4^{2-}</th><th>Mg^{2+}</th><th>Ca^{2+}</th><th>K^+</th><th>CO_3^{2-}</th><th>Br^-</th></tr><tr><td>mg ion per kg sea water</td><td>1900</td><td>10500</td><td>2655</td><td>1350</td><td>400</td><td>380</td><td>140</td><td>65</td></tr></table></td></tr>
<tr><td>Q_9</td><td>Application</td><td>molar concentration</td><td>A 25 gr effervescent tablet contains 1.76% by mass of vitamin C ($C_6H_8O_6$). If the tablet is completely dissolved in water and the</td></tr>
</table>

			solution is diluted to a final volume of 250 mL, calculate the molar concentration of vitamin C.
Q_{10}	Analysis	solution components	In 100 mL of aqueous solution A, there are 2 moles of sodium nitrate, and in 100 mL of aqueous solution B, there is 1 mole of ammonium sulfate. If these two solutions are mixed, which graph correctly represents the change in the moles of ions present in the solution? Explain your reasoning. 
Q_{11}	Analysis	molar concentration	The calcium ion concentration in a solution is 0.4 M. If 0.25 gr of calcium nitrate are added to 5 liters of this solution, what will be the new molar concentration of calcium ions? (Ignore the change in the initial solution volume and assume the solution density is 1 $g \cdot mL^{-1}$.)
Q_{12}	Analysis	dilution	Based on the figure provided, if 70 gr of the large soft drink are mixed with 30 gr of the small soft drink, what will be the mass percent of sugar in the mixture? 

Items of researcher-developed questionnaire were rated on a five-point Likert scale, from "Strongly Disagree" (1 point) to "Strongly Agree" (5 points), producing a total possible score range of 30 to 150, where higher scores indicated a greater level of creative thinking.

Item	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
	5 Points	4 Points	3 Points	2 Points	1 Point
Fluency					
1. When I encounter a new problem, I can generate several different solutions in a short amount of time.					
2. I usually come up with many ideas for completing a task.					
3. When facing a problem, I suggest multiple options before choosing the final solution.					
4. I can provide various and diverse examples for a scientific topic.					
5. When given time to think, I am able to generate a large number of ideas.					
6. I prefer to find multiple and different ways of doing things rather than relying on a single approach.					
Flexibility					
7. If one solution does not work, I can quickly try a different approach.					
8. When learning difficult topics, I am able to shift my perspective.					
9. I enjoy examining problems from different angles.					
10. When someone offers a different opinion, I can accept it and think about it.					
11. When chemistry lessons become difficult, I adjust my learning strategy.					
12. I can answer a scientific question from multiple viewpoints.					
Originality					
13. I usually come up with ideas that others do not easily think of.					
14. When doing assignments, I like to try new and unique methods of my own.					
15. In class, I often give answers that are different from those of others.					

16. For solving scientific problems, I sometimes propose solutions that others have not considered.					
17. My ideas usually have originality and creativity.					
18. When a familiar topic is discussed, I try to view it from a new perspective.					

Elaboration

19. I can develop simple ideas by adding explanations and details.					
20. When I have an idea, I can expand it step by step.					
21. I usually provide complete and detailed explanations in my answers.					
22. If asked, I can turn an initial concept into a fully developed one.					
23. I like to add depth to scientific ideas rather than giving short answers.					
24. When writing or thinking, I try to include useful and relevant details.					

Sensitivity

25. When studying chemistry, I quickly notice ambiguous or inconsistent points.					
26. I can identify problems or errors in solutions.					
27. When a problem is presented, I often detect its weaknesses or the parts that require further examination.					
28. When observing experiments or simulations, I pay close attention to small changes and details.					
29. When faced with a problem, I can identify its key and challenging components.					
30. I usually raise important questions about a problem before trying to solve it.					