Preserving Concept Consistency in Experiential Learning

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ABSTRACT

Experiential learning has become more diverse and popular in its applications to different learning concepts. However, for concepts which are difficult to understand, using experiential learning leads to a disconnect between the experience and the conceptualization stages, resulting in confusion and failure of learning the concept. To preserve this connection, we propose a novel approach of using an immersive, first-person experience to extract the underlying core element of the concept. We designed a user study to evaluate the effectiveness of the student's learning. From the study, our approach had a stronger effect on the student's learning improvement compared the standard experiential approach.

KEYWORDS

Education, Experiential Learning, Physics Education, Teaching, Human Interface Technologies

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1 INTRODUCTION

It is often challenging to interpret abstract knowledge in a tangible and intuitive way. Students, especially K-12, often struggle with obscure concepts in STEM education. Therefore, educators are striving to provide a more engaging and effective learning experience for students. Experiential learning (i.e. learning through the reflection from experiences or "learning-by-doing")[8] has been proven effective in science and engineering education [3, 12]. One famous example of experiential learning is the Kolb's learning cycle [14] shown in Figure 1, in which students actively get involved in activities, and construct the concept from their observations and reflections from the activities. Advancements in digital technologies such as Web, Virtual Reality (VR), Augmented Reality (AR), Mixed Reality (MR) have created tools and interactions to enhance learning experiences [15–17, 24].

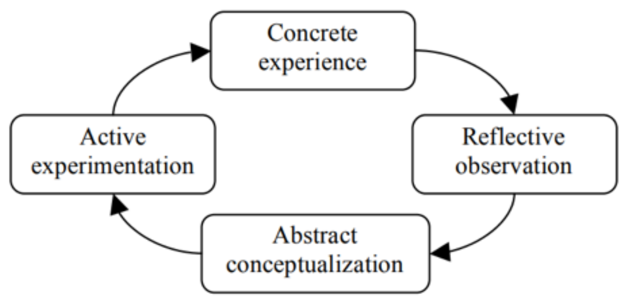

Figure 1: Kolb's experiential learning cycle.

However, there experience reflection process raises an important question: Do students interpret, reflect, and conceptualize the experience in the same way as the teachers or textbook are intended to? Although there have been advanced approaches (see Related Work) aiming to enhance the learning experience, in the process of reflection and theorization, we argue that there is a concept inconsistency that results in ambiguity when students attempt to transform their experiences to theories. Therefore, we aim to develop a novel approach of designing an immersive learning experience that allows an abstract engineering concept to be experienced by the learner at first hand, from the first-person perspective without breaking the concept consistency during the theorization stage.

Our main contributions are:

- A novel learning activity to help student learn physics concepts through experiential learning
- A user study to evaluate whether the learning activity is effective in improving user's learning outcome

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2 RELATED WORK

Techniques for Enhancing Learning Experiences

It has been an ongoing effort to create concrete, intuitive, and hands-on experiences to help students interpret, reflect, and relate their learning activities to the concepts intended to be taught. Abstract knowledge is sometimes taught by using analogies as a cognitive aid to allow the student to map from what they can easily reason or observe to the concept that seems less apparent [5, 14, 20]. Learning activities can be designed based upon the analogy. For example, the experiment shown in Figure 2 uses the DC circuit water analogy (Figure 2 Left) [2, 13], creating an experience to allow students relate water pressure measurement using the U-Tube to voltage measurement using the voltmeter. By the end of the experiment, students are expected to reflect their experience and conceptualize the electric potential difference from observing the water pressure difference. The analogy-based experience can also be created using computer simulations [10].

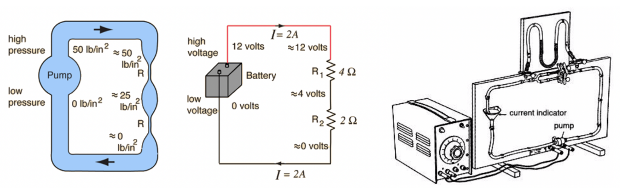

Figure 2: DC Circuit Water Analogy (Left) and Water pressure measurement to help study the concept of voltage difference (Right).

The advancement of VR and AR enriches students' experience of visualizing the flow of electrons in an electric circuit [4, 7, 22, 23] and learn about its characteristics like Ohm's law [19]. Gamifying the learning experience also allows students to be engaged by relating everyday things to the concepts such as circuit-building [9] and energy interventions [11, 21]. Tangible user interfaces are built to help students understand basic astronomical phenomena [1].

Concept Inconsistency in Experiential Learning

While existing approaches (including those invoking advanced AR and VR) have been attempting to create an immersive, interactive, and intuitive learning experience, we argue that there can be a concept inconsistency between their *experience* stage and the *conceptualization* stage. This inconsistency can lead to confusions when a learner transforms the observation into concepts in the *conceptualization* stage. As an example, Beheshti et al. presented an AR-based exhibit *Spark* to help learners understand how electrons flow through a circuit [4]. In their design, the user can hold a tablet above the circuit to observe the moving electrons (see

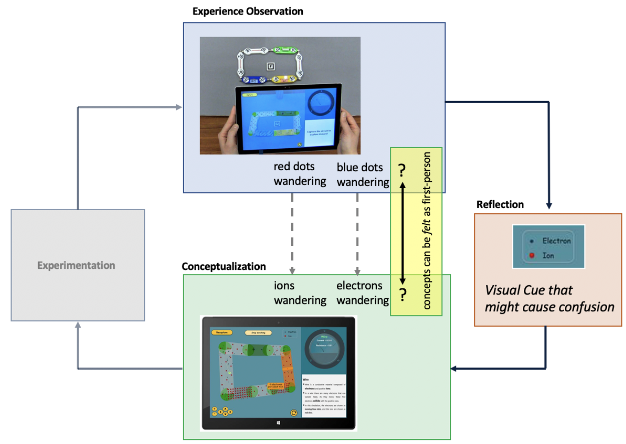

Figure 3: Concept inconsistency in the process of learning electron flowing through a circuit using the AR exhibit *Spark*designed by Beheshti et al.[4].

Figure 3). The interface also provides a legend explaining red dots as Ions and blue dots as Electrons, helping the learner establish a one-to-one correspondence between the simulation and the original concept. However, the red dots and the blue dots perceived by the learner are not the actual ions and electrons. They are different objects in many ways (e.g., such as their shape and color). A student may raise the question *Are ions red?* or may quickly come to the wrong conclusion that *Ions are red dots.* Each of the dashed arrows in Figure 3 represents the risk or ambiguity that a student might fail to relate what they have experienced to what they need to learn intended by the instructor or the user interface.

The DC circuit water analogy (Figure 2) can also lead to similar ambiguities or confusions. When complexity is added to the system, (the power supply and electric wires) students might get confused about the role of each component: *Is it intended to help me learn, or it is the thing I need to learn?* Therefore, we need a new relation that connects the concept the learner senses as a first-person from learning experience with the concept he/she is aiming to learn.

The novelty of our work is the establishment of a preserved concept consistency across two concept spaces (the yellow bridge shown in Figure 3). The concept should be directly perceived by the learner from a first-person perspective: What the learner feels in the learning experience is the concept that he/she will learn. For example, if we want to teach a concept about "energy loss", we design a learning activity to let learners feel some "energy losses" in real-life, then we guide them through a reflection process that help them model and conceptualize the energy loss in a circuitry. In the next section we discuss the design and implementations of our approach.

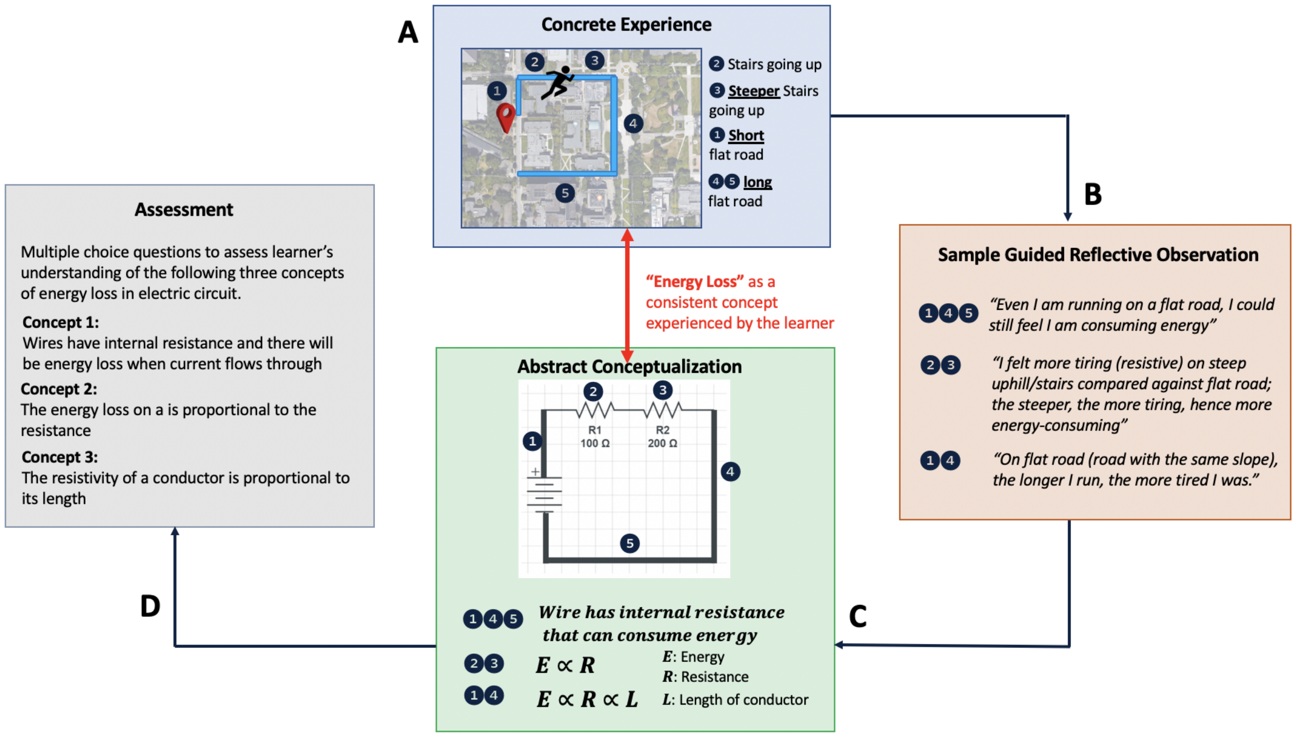

Figure 4: Proposed Learning Process.

3 DESIGN

Learning Experience Design

Our design lies in the context of physics education, targeting students who have limited background knowledge and practices about electrical circuits. We aim to create an experience that can be incorporated into Kolb's Learning cycle with the three learning objectives. By the end of the learning process, students should be able to:

- Explain why the total energy loss of a resistive circuit is larger than the sum of all resistors' energy losses
- Describe how the resistance value of a resistor can have an impact on its energy loss
- Recognize a conductor's resistance is proportional to its length

The experience starts with an outdoor running session, in which students are asked to complete a route consisting of five segments (Step A in Figure 4). Each segment has a geographical feature (e.g., steepness), and the learner is expected to feel distinguishable levels of energy consumption on their body in each segment. The running is followed by a reflection session guided by an instructor, who helps the learner carefully recall the running they have completed (Step B). The reflection also incorporated a side-by-side comparison of the route and a resistive circuit representation mapped based on the geographical features (Figure 5 Right). Then, the student works with the instructor to transform their reflection into three concepts (Step C). Finally, multiple choices questions are used to allow students to apply these concepts to solve related problems (Step D).

Interface Prototype Design

A portable prototype device (Figure 5) is designed to help students navigate through the route in the running session. It provides turn-by-turn navigation based on the user's current location. A graphical interface is created to display the map-circuit side-by-side comparison for learner's reflection.

Figure 5: A Portable Device Prototype (Left) with a Navigation Interface and A Learning Reflection Interface (Right).

4 STUDY: EFFECT OF IMMERSIVE ACTIVITY IN EXPERIENTIAL LEARNING

Pilot Study

In the initial phase, we first performed a pilot test with two participants to validate the methods of our user study and the effectiveness of the prototype design. Feedback from the participants was mostly positive, but one participant mentioned that one section of the experience felt more like a resistive element as opposed to a wire element. As a result, we re-analyzed section five and decided to modify it to a resistive element instead.

Participants

10 participants (6 male, 4 female), aged between 20 to 40 were recruited for this study. All participants had some level of background knowledge with regards to power loss and electric circuit concepts prior to the study.

Design

A between-subjects design was used to evaluate between the proposed method and the baseline method. Variables for the design are as follows:

- Independent Variable: The proposed experience method and the baseline learning video method.
- Dependent Variable: (Objective) The amount of improvement in knowledge before and after the study and (Subjective) Score rating through a subjective questionnaire.
- Controlled Variable: The route users run/watch for the study and its transferrable circuit elements.

Procedure

Prior to starting the study, participants filled out a pre-assessment form relating to the concepts of energy loss with wires and resistance. Details of the assessment are explained in the Assessment Evaluation subsection below.

During the study, based on the method of study (proposed or baseline) they were assigned to experiment with, participants performed a task in the Tasks section described below.

After the study, participants filled out a post-assessment. The post-assessment consists of the same questions as the pre-assessment, unchanged to assess their improvement in knowledge.

Completing the post-assessment, participants filled out a questionnaire for their subjective response based on their experience with the assigned method in the study. Questionnaires evaluated responses based on a 7-point Likert scale.

Tasks

The tasks performed varies based on the method of study (proposed or baseline) the participant was assigned.

Proposed method: Participants were asked to run the pre-designed route to experience the physical energy loss connection to the energy lost in an electric circuit. The pre-designed route consists of 5 sections, starting from Marine Drive residence in Lower Mall and finishing by the fountain on Main Mall, shown in Figure 5 (Left). This task is performed with the assistance of our designed prototype. Afterward, participants viewed the electric circuit elements corresponding to the route ran, shown in Figure 5 (Right), to reflect on their experience and establish a connection between the experience and the concept.

Baseline method: Participants were asked to watch an 8-minute video recording of the route which the participants in the proposed method ran and the running motion of the user. Additionally, sessions were accompanied by audio recordings of how the participant felt during the experience. Afterward, participants also viewed the electric circuit elements corresponding to the route ran to understand and establish a connection between the experience and the concept.

Assessment Evaluation

The assessment consists of 4 questions (3 selection-based, 1 design-based). For the selection-based questions, participants were required to select an option or provide an order from multiple choices. Additionally, they were to explain the reason they selected the answer. The selection-based questions focused on two main concepts: 1) greater resistance creates greater energy loss and 2) Wires in circuits also have energy loss. Figure 6 shows an example question of the second concept, with the correct answer and explanation. For the design-based question, participants were given a set of circuit elements and asked to add those elements into a fixed-sized space in a way which minimizes energy loss. The purpose of the design-based question assesses the participant's understanding of energy loss from wire lengths at a deeper level. The total possible score in each assessment is 7 points (4 points for answers, 3 points for explanation). Each question and answer were graded out of 1 point (correct = 1 point, wrong = 0 points, partially correct = 0.5 points).

Apparatus

The tasks performed varies based on the method of study the participant was assigned.

For the proposed method, the set-up for the study required the use of the system designed (details in the Design section). Additionally, the location for the pre-designed route needs to be accessible.

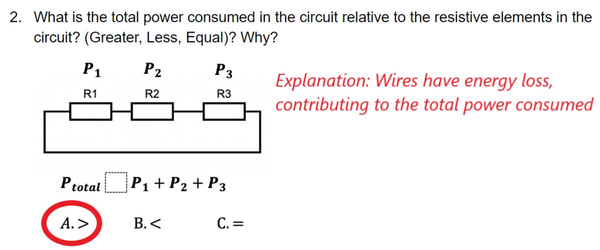

Figure 6: Sample Assessment Evaluation

For the baseline method, a laptop with a MPEG-4 player application is required to play the video. Specs of the laptop have no specific requirements, and no further equipment is required.

Hypothesis

We hypothesize the following effects to be seen from the results of the study:

[H1] *Effect of Learning*: The proposed experience method will show more improvement in learning than baseline video method.

[H2] *Concept Connection*: Users feel a stronger connection in experience with the proposed experience method than baseline video method.

Results

Effect of Learning.

Results for the effect of learning was determined based on the pre-assessment and post-assessment scores. Table 1 shows the results of the evaluation for each participant's pre-assessment and post-assessment, respectively. The effect of learning amount was determined based on the improvement between the participant's pre-assessment score and their post-assessment score. The improvement between the score was evaluated as the absolute score increase from their post-assessment score with their pre-assessment score, shown in Table 2. A paired-samples t-test was performed between the two methods to evaluate the effect of learning score in Table 2. The reported effect between the proposed experience and the baseline video was calculated to be arguably significant ($T(4) = 2.138, p = 0.099$). At the 90% confidence level, it is proven that the connection created between physical energy loss and energy loss in electric circuits significantly improves the student's ability to learn the concept.

A key observation in Q1 column of Table 1 shows that more participants using the proposed method improved than the baseline method in the post-assessment. This observation is extremely positive because Question 1 focuses on the concept of increasing resistance leading to more significant power loss, which is the critical concept we tried to deliver

Table 1: Assessment Evaluation Results

Pre-Assessment						
Participant	Method	Q1	Q2	Q3	Q4	Total
1	Proposed	0	1.5	1	0	2.5
2	Proposed	2	2	0	0.5	4
3	Proposed	1	0	0	0.5	1
4	Proposed	0	0	1	0.5	1
5	Proposed	1	2	2	0	5
6	Baseline	0	0	0	1	0
7	Baseline	2	0	0	0.5	2
8	Baseline	1	1	1	0.5	3
9	Baseline	1	0	1	1	2
10	Baseline	2	2	0	0.5	4
Post-Assessment						
Participant		Q1	Q2	Q3	Q4	Total
1	Proposed	1	2	1	0.5	4
2	Proposed	2	2	2	0.5	6
3	Proposed	1	0	0	0.5	1
4	Proposed	2	0	0	0.5	2
5	Proposed	2	2	2	0.5	6
6	Baseline	1	0	0	0.5	1
7	Baseline	2	0	1	0.5	3
8	Baseline	1	1.5	1	0.5	3.5
9	Baseline	2	0	1	0.5	3
10	Baseline	2	2	0	0.5	4

Table 2: Effect of Learning Improvement

Participant	Method	Improvement
1	Proposed	2
2	Proposed	2
3	Proposed	0
4	Proposed	1
5	Proposed	1.5
6	Baseline	0.5
7	Baseline	1
8	Baseline	0.5
9	Baseline	0.5
10	Baseline	0

in this learning module. An interesting observation can be made from the design-based question (Q4 column of Table 1), where for the proposed method shows improvement for P1 and P5 and the baseline method showed regression for P6 and P9. Additionally, all participants answered partially correctly in the post-assessment. This may indicate either that the baseline method is misleading the participant's learning of the concept, or that the question was too deep and confusing to understand. However, we decided to keep the results as all participants were able to answer the question accurately.

Concept Connection.

The concept connection is measured subjectively by the participant responses in the post-study questionnaire. The questionnaire consists of 5 questions, targeting the participant's satisfaction and their opinion on the effectiveness of the learning method. Results were averaged by questions, displayed in Figure 7. A paired-samples t-test was performed between the two methods to evaluate the concept connection. The reported effect between the proposed experience and the baseline video was calculated to be insignificant ($T(4) = 0.356, p = 0.740$).

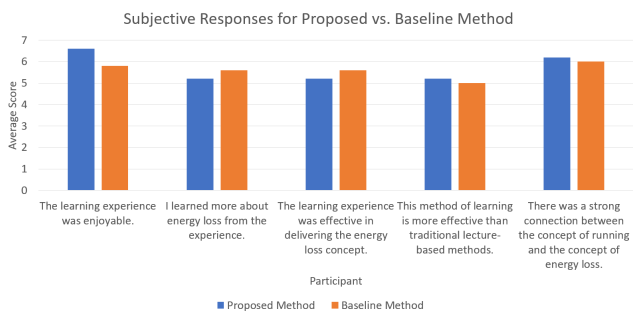

Figure 7: Concept Connection Results

Summary

The results are summarized based on our hypothesis:

[H1] *Effect of Learning*: Arguably supported. There was significance at the 90% confidence level proving our proposed method is more effective for learning.

[H2] *Concept Connection*: Not supported. The subjective responses show relatively equal scores between the proposed and baseline method.

5 DISCUSSION

While the effect of learning has some level of significance, there are several factors to be considered which may either improve or weaken this result. One such factor comes the undiscovered effect for the level of expertise impacting the amount of improvement. A participant with a highly knowledgeable background of the energy loss concept may not produce as effective results as a novice with little background. While we attempted to balance its effects as much as possible in creating an even average diversity between the participants of the two methods, there are still subtle differences. However, though undiscovered, this factor may not have high implications. Table 1 shows that both the novices and expert participants for this study improved at a same pace.

Another consideration is the design of the assessment, as proven by the observation made for the answers in design-based question. There are multiple possible explanations for the results, but this example implies that the depth and type of question may be interpreted differently by participants, and that, despite using explanation points in the assessment to reduce the effect of guessing answers, some questions may have been answered correctly by chance. This is also proven by the explanations made in the assessments, as in many cases participants did not provide a valid explanation despite answering the question correctly. As a result, the depth of this assessment was partially limited by the depth of the participant's explanations.

For the subjective responses of the concept connection, although insignificance was proven by the results, fundamental discoveries were made in this direction. Even though the average scores from the questionnaires were relatively equal, when describing the proposed method study to participants using the baseline method, they believed the proposed method would create a better connection of the learning concept. In an interview with P10, he/she stated *if I were to experience the running, I would feel a better correlation to the energy loss.* An explanation for the similar subjective score may be instead due to diversity limitations in a 7-point scale, which generalized most ratings to fall under a general *good* category of 5-6 scores as responses.

Overall, there is a major limitation in performing a between-subjects study to evaluate the effect of learning. Individuals have very diverse learning speeds, and the effectiveness of a learning method varies based on preferences for a learning method. This effect is partially controlled as the proposed method, and baseline method performed the study under the same context, but individual differences still exist. It is uncontrollable that some people learn better through video, while others learn better through experience.

6 CONCLUSION AND FUTURE WORK

In this study, we proposed a method to resolve the inconsistency gap between the experience and conceptualization. Results of our study showed that this method has helped users understand the learning concept better, proving significance at the 90% confidence level. Despite the quantitative results, in subjective responses, we discovered that users did not feel that this method connected the gap effectively, though users testing the baseline solution stated they would have preferred to use the proposed method. Time and resource limitations restrict the project prototype to test this novelty concept through energy loss and running only. However, this idea can be applied to other educational concepts using various experience-enhanced activities. For example, weight-lifting can be used to lecture Newton's second law.

While varying the mass of the weights lifted, users can experience various amounts of force based on the respective mass. Another, wider-scaled concept, uses the experience of driving as a method to educate current flow in a circuit. Users driving represent electrons which can feel the slowness of the current based on the amount of traffic in each route. In future designs, we plan on developing methods for such other concepts to bridge the inconsistency gap and evaluate whether the effect of improvement holds consistency.

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