Inquiry-based activities and their effects on students' ability to explain related problem scenarios

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This research investigated the impact of several structured inquiry experiments in mechanics and heat on introductory college physics students' ability to solve or make sense of problem scenarios. The students performed experiments where they were guided in discovering for themselves the physical concepts or principles rather than having them verify concepts/principles as in traditional lab classes. At the end of each laboratory activity, students were asked to answer problem scenarios with solutions or answers requiring a direct application of the physical concepts investigated in the laboratory experiment. Our preliminary results indicate that students are able to use the concepts learned from the laboratory activity in explaining problem scenarios only in some topics (e.g. thermal expansion) but not in other topics (e.g. momentum conservation).

I. INTRODUCTION

Most introductory college physics students have difficulty with conceptual questions that require them to apply physical principles. Research had shown that inquiry-based teaching facilitates the development of more solid conceptual understanding [1-3] and help develop higher-ordered thinking skills among students [4-5]. Moreover, physics laboratories are now becoming more focused on how students investigate, collect data and make conclusions from their results rather than simply verifying facts or principles. Students in an inquiry-based physics laboratory make connections between physical phenomena and abstract representations [6].

We have rewritten our laboratory manuals in introductory algebra-based physics 1 to make it more discovery-based. Ample opportunities were provided to students to organize, analyze, reflect on the experimental data gathered, and generate conclusion(s) supported by experimental data they have collected. An example of the lab activity on linear momentum is provided in the methodology section.

In this study, we investigated students' ability to explain problem scenarios with solutions/answers requiring direct application of the physics concepts studied in the inquiry-based laboratory activities.

II. THEORETICAL BACKGROUND

Our research is anchored on the tenets of analogical transfer. Analogical transfer studies involve training on one task and testing on new task that is an analogue of the first task [7].

Transfer can be classified either as specific (near transfer) or non-specific (far transfer) [8]. Specific transfer

occurs when there is a clear similarity between the stimulus complex encountered in one situation and the stimulus complex encountered in another situation. This is in line with the principles of mastery learning. On the other hand, non-specific transfer occurs when there is no obvious relationship between the stimulus properties of two learning events, but the acquisition of one influences the acquisition of the other.

The contemporary perspectives of transfer [9-10] view transfer as a dynamic process. Lobato [10] proposes a student-centered perspective that studies the "creations of relations of similarity between the learning and transfer contexts" as perceived by the learner. Bransford and Schwartz's notion of transfer as "preparation for future learning" emphasizes whether a student can "learn to problem-solve in the transfer context." Transfer is facilitated by scaffolding in both the learning and transfer contexts. An implication of the aforementioned transfer perspectives is that one should view transfer from the point of view of students rather than from the researcher's perspective.

A pedagogical approach introduced in physics classrooms to help students gain a deeper conceptual understanding of the material learned and help students interpret and understand real-world problems that require higher-ordered thinking skills is inquiry-based instruction. Banchi and Bell [11] identified four levels of inquiry depending on the amount of information given to the student. It includes confirmation inquiry, structured inquiry, guided inquiry, and open inquiry. The goal of confirmation inquiry is for students to confirm a principle through experiments where results are known in advance. Traditional cookbook laboratory falls into this category. In structured inquiry, students investigate a problem through an instructor directed procedures but results are not known in advance. In guided

inquiry students are provided only with the problem and they design their own procedures. Lastly, in open inquiry students come up with their own questions and method of investigation. The laboratory activities that we developed fall into the structured inquiry category.

III. METHODOLOGY AND DATA ANALYSIS

Figure 1 shows a portion of the laboratory handout on momentum.

Purpose

In this lab, you will investigate the momentum of colliding carts.

Materials

Dynamic cart (plunger cart), collision cart, cart launcher, 500 g mass, PASCO track and attachments, 2 photogates & photogate attachments, 2 PASCO Five-Pattern Fences, PASCO data acquisition system, table clamp, post

Principles

An object with mass m moving with a velocity v has a linear momentum p equal to the product of the mass and velocity. Symbolically, we can write $\vec{p} = m\vec{v}$. The total momentum of a system of N bodies is obtained by computing the vector sum of the momentum each of the N bodies comprising the system:

$$\vec{p}_{total} = \sum_i^N m_i \vec{v}_i = m_1 \vec{v}_1 + m_2 \vec{v}_2 + \cdots + m_N \vec{v}_N$$

FIG 1. Sample lab handout.

We incorporated questions to make students reflect on the data they are collecting. The following are some of the reflection questions in the momentum lab:

- How does the momentum of the system before collision compare with the momentum after collision? Was the momentum of the system conserved? Justify your answer.
- Will the momentum of the system be conserved if we put additional mass on the target cart?

Moreover, we provided opportunities for students to apply the underlying physics principle(s) being investigated. Below is an example of a problem scenario that students were asked to answer after completing the guided inquiry laboratory activity.

“While watching a movie about a superhero, you notice that the superhero hovers in the air and throws a piano at some bad guys while remaining stationary. What is wrong with this scenario?”

Using the existing laboratory experiments in mechanics and heat, this research investigated the impact of some selected structured inquiry experiments on introductory college physics students' ability to solve or make sense of related problem scenarios

We employed qualitative data collection (e.g. document review) and analysis technique (thematic analysis) to determine the impact of inquiry-based experiments on students' ability to answer or make sense of related problem scenarios. The accomplished laboratory handouts of students

enrolled in introductory algebra-based physics were secured and analyzed. Approval from appropriate offices were secured to allow the research team to get copies of the student laboratory handouts. A total of seventy (70) completed handouts from the momentum lab and sixty-four (64) from the thermal effects lab were secured and utilized in this paper.

A phenomenographic approach [12] was adopted to analyze the data. Significant statements were extracted from students' verbatim answers to the different questions in their laboratory handout. A second layer of analysis was then conducted to categorize student responses. Three researchers made their initial categorization of student responses and after a thorough discussion came up with consensus in categorizing student responses as listed in the results section.

To address the validity of our findings and interpretations, we employed researcher triangulation technique [13] whereby multiple investigators were involved in the analysis and interpretation of data.

IV. RESULTS & DISCUSSION

Most of the laboratory experiments performed during the whole semester require the students to compare two numbers (e.g. slope of velocity time graph and acceleration, initial and final momentum, etc.). The first lab activity introduces students to the analytical tools they need to analyze data. Students are required to use Data Studio or Excel to plot data and determine the appropriate trend line for certain relationships investigated (e.g. variation of centripetal force with mass). In addition, it was emphasized in the introduction lab that when comparing two values, students need to take the difference and divide it by the standard deviation of the measurements (σ). Measurements that are within $\pm 3\sigma$ of some expected result are deemed consistent.

Of the 10 laboratory experiments that the students performed, we selected two (2) for data analysis in the context of this paper. In the following section, we present the results of the analysis conducted on the Linear Momentum Lab and Thermal Effects Lab.

A. Linear Momentum Experiment

Below are the typical student responses on questions about the momentum before and after in the case of: (a) an elastic collision between two carts with the same masses, (b) an elastic collision between two carts with different masses, (c) two carts initially together then move away from each other.

“Yes, the momentum of the system before and after the collision are equal and are conserved. The difference is within $\pm 3\sigma$ ”

“The momentum of the system is conserved because on the elastic comparison table, the 1st column [initial momentum] and 3rd column [final momentum] are within $\pm 3\sigma$ about the same”

The above responses show that students found the initial momentum of the carts undergoing elastic and inelastic collisions to be consistent with the final momentum of the system. This means that their data supported the conclusion that the momentum of the carts is conserved.

Problem Scenario 1 (Momentum)

“While watching a movie about a superhero, you notice that the superhero hovers in the air and throws a piano at some bad guys while remaining stationary. What is wrong with this scenario?”

Six (6) categories of students’ explanations on problem scenario 1 (superhero + piano) emerged from the analysis of the verbatim statements of the students gathered from seventy (70) laboratory reports. Below are the categories of responses and a sample of response for each category.

1. **Momentum Conservation** (22 students, 31%). Students explained that the superhero will move back because the momentum of the system should be conserved.

“The superhero should travel back after throwing the piano because the momentum of the system should be conserved. If one object travels forward, there must be another that travels backwards.”

2. **Mass explanation** (5 students, 7%). The mass of the piano will cause the superhero to move back.

“The superhero is supposed to move back also because of the lack of mass of the piano.”

3. **Force and Mass** (3 students, 4%). The greater mass of the piano will require force to be exerted on it, thus making it not possible for the superhero to remain stationary.

“In this scenario the superhero should not remain stationary when throwing a piano to the bad guys. Since the piano has greater mass than the superhero, he needs to exert more force in order to throw the piano. This in turn means the superhero should not remain stationary.”

4. **Newton’s Laws of Motion** (2 student, 3%). Because of Newton’s laws of motion, the superhero should move back.

“The superhero should have moved back. If he is throwing something forward, Newton’s Law says that the piano should push back a force moving our superhero back.”

5. **Action-Reaction explanation** (35 student, 50%). Since the superhero exerted a forward force on the piano, then the piano should push back on the superhero.

“The superhero is supposed to move in the opposite direction as he threw the piano due to the fact that for every action there is a reaction in the opposite direction.”

“The superhero would move in the opposite direction of the piano, because the force of the piano would push him back.”

6. **Gravity explanation** (4 student, 6%). The superhero and piano will be pulled down by gravity.

“The piano is heavier than the superhero he should fall. Gravity takes down heavier things faster.”

The above categories of responses show that only 31% (22 out of 70) of the students used conservation of linear momentum in making sense of the problem scenario involving a superhero throwing a piano forward while remaining stationary. A larger percentage (50%) of the students used the action-reaction concept in justifying that the superhero cannot remain stationary as he throws the piano forward towards the bad guys.

A second layer of analysis of the categories show that there are two themes of explanations for why the superhero cannot remain stationary: (1) momentum explanation and (2) force explanation. About one-third of the students explained that the superhero should move backward because the momentum of the superhero and piano must be conserved. On the other hand, about two-thirds of the students used forces to explain why the superhero should move back.

B. Thermal Effects Experiment

In this laboratory activity, the students performed three experiments on: (1) how the temperature of water changes as it is made to boil and while it is boiling, (2) conservation of thermal energy (calorimetry), and (3) heating up of a metal ring and ball.

A review of the students’ responses specific to the above objectives reveal, respectively, that most of the students conclude that when water is boiled, its temperature increases until it reaches the boiling temperature and does not increase anymore once it starts to boil; the thermal energy of cold and hot water mixture is conserved; and that when the metal ring is heated up it expands allowing the metal ball to go through it easily.

Problem Scenario 2 (Thermal Effects)

Why are roads constructed with gaps on them?

Four (4) categories of explanations emerged from the analysis of data from 64 laboratory reports.

1. **Expansion + Damage Prevention** (35 students, 56%). Students explained the need for the gaps in terms of the expansion of the road to prevent either cracking or breaking apart.

“Gaps are needed because when temperatures are high, the pavement will expand. If a gap is not present the pavement will crack upon attempting to expand.”

- 2. Expansion** (22 students, 35%). Students in this category explained the need for gaps to allow for the expansion of the road but nothing is mentioned of the consequence of the expansion.

“To allow the materials in roads to expand or contract depending on the temperature.”

- 3. Thermal energy transfer explanation** (1 student, 2%). One of the students explained the need for gaps so thermal energy can be transferred.

“So that thermal energy can be transferred.”

- 4. Gaps Expand** (4 students, 6%) In this category, student mentioned that it is the gaps that will expand thus, preventing the damage to the road.

“Because of the heat from the sun. Due to the increased heat, the gap will expand and if it wasn’t there the roads will crack.”

In contrast to the linear momentum lab, majority of the students (57 out of 64) correctly used the concept of thermal expansion to explain the need for the gaps on roads.

V. CONCLUSIONS AND IMPLICATIONS

Our results are consistent with other research showing the context dependence of transfer [7]. It can be seen that majority of the students were able to use or apply the concept of thermal expansion in explaining the gaps on roads and yet majority of them did not readily apply the concept of conservation of linear momentum in explaining why the hypothetical superhero cannot remain stationary while throwing a piano forward. For the latter group, majority of the students (66 out of 70) seem to recognize that the superhero is supposed to move back opposite to the thrown piano. However, only 22 of these students used conservation of linear momentum to explain why the superhero should

move backward. A greater percentage of students (about 60%) used the concept of force as an explanation. It may be possible that in this case, students had developed a deeper understanding of forces which made them use this reasoning more readily.

Our results further show that students do associate previously learned physics concepts in making sense of the problem scenarios. However, when presented with a scenario that has multiple plausible answers we see that students do not necessarily apply the more recently learned concept through discovery-based experiments (plunger & dynamics carts) to the transfer context (superhero & piano) even though they seemed to recognize the similarity of the situations. We could see that students tend to use concepts that they are more familiar with in explaining new situation presented to them. This is consistent with studies on dynamic transfer [13].

VI. FURTHER WORK

Further research can be done to understand in more detail why students readily apply some physics concepts (e.g. thermal expansion) but not others (e.g. linear momentum conservation) in making sense of “near transfer” situations or scenarios. We are currently exploring scaffolding activities that could facilitate the use of target content knowledge learned through discovery-based experiments to a transfer situation in the context of linear momentum conservation.

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- [1] L.C. McDermott and E.F. Redish, Am. J. Phys., **67** (9), September 1999, pp. 755-767.
- [2] P.W. Laws, *Workshop Physics Activity Guide*, New York, Wiley. 1997
- [3] R.A. Ross, *Proceedings of the 2000 Frontiers in Education Conference*, Kansas City MO, (2000).
- [4] J.C. Marshall and R.M. Horton, School Science and Mathematics, 111: 93–101. (2011).
- [5] G. V. Madhuri, V. S.S.N Kantamreddi, and L. N.S. Prakash Goteti, European Journal of Engineering Education, **37** 2 (2012).
- [6] <http://www.jstor.org/stable/40188760>. Retrieved 11/21/2016.
- [7] S.M. Barnett & S.J. Ceci, Psychological Bulletin, 128(4), 612-637 (2002).
- [8] J. M. Royer., Theories of the transfer of learning. Educational Psychologist. 14, 1(1979).
- [9] J.D. Bransford and A. L. Brown. How People Learn: Brain, Mind, Experience, and School. Washington, DC, National Academy Press. (1999).
- [10] J. Lobato, Educational Researcher, 32(1), 17–20. (2003).
- [11] H. Banchi and R. Bell. The Many Levels of Inquiry. Science Children. pp.26-29. (2008).
- [12] F. Marton, Journal of Thought 21: 29-39. (1986).
- [13] J.W. Creswell, Educational Research. Pearson Education, Inc. Upper Saddle River, NJ, pp.252-253, (2005)
- [14] E.D.Corpuz, & N.S. Rebello, Res Sci Educ (2017). <https://doi.org/10.1007/s11165-017-9650-2>