Using Physics Jeopardy Problems to Assess College Students' Transfer of Learning from Calculus to Physics[$]

Lili Cui[1], N. Sanjay Rebello[1] and Andrew G. Bennett[2]

[1]*Department of Physics, 116 Cardwell Hall, Kansas State University, Manhattan, KS, 66506-2601*
[2] *Department of Mathematics, 138 Cardwell Hall, Kansas State University, Manhattan, KS, 66506-2602*

Abstract. This research investigated students' transfer of learning from calculus courses to an introductory physics course using non-traditional physics Jeopardy problems. We used semi-structured think-aloud interviews to assess the extent to which students transfer their calculus knowledge when solving Jeopardy problems. Jeopardy problems present interviewees with an intermediate step in the form of a mathematical integration and ask students to come up with a physical scenario relevant to the integral provided. Results indicate that students often had difficulty taking apart the given problem and constructing the corresponding physics situation.

Keywords: physics education research, transfer of learning, problem solving, calculus, Jeopardy problems.
PACS: 01.40Fk

INTRODUCTION

This study is a continuation of our previous efforts on assessing transfer of learning. Transfer of learning has often been referred to as the central goal of education (e.g. [1]). In this study we focus specifically on transfer from calculus to physics. Since calculus is a necessary preparation course for calculus-based physics, how students transfer their knowledge learned in calculus can be critical to their learning in physics. In the previous study, we assessed transfer using traditional physics problems.

In this study, we used non-traditional physics Jeopardy problems [2] to investigate transfer of learning by assessing whether students could deconstruct the information provided in the Jeopardy problem and construct a physical situation corresponding to the given information. While traditional physics problems involve applying previously learned ideas to a problem, Jeopardy problems involve constructing new ideas to solve the problem. Unlike some 'end-of-chapter' problems, the students cannot apply a pre-constructed schema or internal problem representation to solve Jeopardy problems. Because these problems are unfamiliar to students, they have to construct or reconstruct their internal problem representation to solve these problems. Thus, the main research question investigated by this study was: *To what extent can students reconstruct or deconstruct the provided external calculus representation to create an equivalent physical representation of the situation*?

RELEVANT LITERATURE

Transfer is often defined as the ability to apply what has been learned in one context to a new context (e.g. [3]). Contemporary perspectives describe transfer as a dynamic construction of associations between the two contexts – the prior learning context and the present target context, mediated by several factors. [4] For this study graduated prompting is considered an effective way to assess transfer. [5]

Our previous research [6] results indicated when solving traditional end-of-chapter physics problems, students were able to retain their calculus schemas and they believed that for the most part their calculus class had provided them with adequate knowledge and skills required for physics. Students acknowledged they had difficulties setting up calculus-based physics problems. These difficulties included: deciding the appropriate variable and limits of integration; not being clear about the criteria which determined whether calculus is applicable in a given physics problem. Students also tended to use oversimplified algebraic relationships to avoid using calculus because

[$] This work is supported in part by NSF grant DUE-0206943

they did not understand the underlying assumptions of the relationships.

Physics Jeopardy problems [2] require students to work backwards. Instead of constructing and solving equations pertaining to a given physical situation, students are asked to construct a proper physical situation from a given equation or graph. Van Heuvelen [2] believed Jeopardy problems ensure that "students cannot use formula-centered, plug-and-chug problem solving methods, rather they must give meaning to symbols in the equation" and "help students to learn to translate between representations in a more robust manner."

METHODOLOGY

To investigate transfer, which is characterized as a dynamic process from contemporary perspectives, we conducted semi-structured, one-on-one think-aloud interviews to assess how students transfer their calculus knowledge in physics contexts – in this case Jeopardy problems.

Twelve students who were enrolled in a second-semester calculus-based Engineering Physics (EPII) in Fall 2005 at Kansas State University (KSU) participated in this study. We chose this course because it requires a significant application of integral calculus. Students typically enroll in at least one calculus course before they take EPII.

Each participant was interviewed over two sessions; each lasting about one hour. The interviewee was left alone when solving the assigned Jeopardy problem. Upon completion, we asked interviewees to explain what they had written down and encouraged them to verbalize their thinking process. We also asked them to describe any difficulties they had when solving the problem. To conclude the interview general questions about their calculus background and their application of calculus in physics were asked.

All interviewees indicated they had not previously heard of Jeopardy problems and had not solved similar problems before. To help them become familiar with Jeopardy problems, we used a sample problem by presenting them with the expression (1) below and asking them to construct a physical situation that corresponded to this expression:

$$60kg \times 9.8\, m/s^2 \tag{1}$$

None of them had any difficulty solving this sample Jeopardy problem. They described physical situations such as "s*omething falling, a block with 60 kg, accelerating."* After we were satisfied that students were aware of what a Jeopardy problem was they were asked to solve a total of six Jeopardy equation problems on electricity and magnetism. In each problem, students were provided with a mathematical expression and asked to construct an corresponding physical situation. : Two examples are shown below. Expression (2) represents the electric field due to an arc of charge, while expression (3) represents the magnetic field due to a wire with a non-constant current distribution J(r).

$$2\times\left[\int_0^{\frac{\pi}{6}}(8.99\times10^9\, N\cdot m^2/C^2)\frac{(2\times10^{-10}\, C/m)(5\times10^{-2}\, m)\cos\theta d\theta}{(5\times10^{-2}\, m)^2}\right] \tag{2}$$

$$\frac{\mu_0\int_0^R J(r)\cdot(2\pi r dr)}{2\pi R} \tag{3}$$

We recognized that these expressions are rather hard to work with, and therefore before presenting these problems to students, we presented these problems to faculty and graduate students to gauge the level of difficulty. We understood that Jeopardy problems were rather challenging problems to our interviewees. Our goal was not to find out whether they could correctly solve these problems, rather we were interested in the strategies that they used to attempt these problems

We used a phenomenographic approach to analyze the interview data. Phenomenographic analysis [7] yields a variation of students' ideas rather than researchers' conceptions about students' models. The categories for coding of the interactions emerge from the analysis of the responses. The categories from phenomenographic analysis were synthesized using thematic analysis until the dominant themes emerged..

RESULTS AND DISCUSSION

We observed that most interviewees (10 out of 12) had several difficulties solving the Jeopardy problems. They typically wrote down very little on the paper provided during the interview. This behavior was different from traditional, end-of-chapter physics problems, where students often wrote down each step. It usually took an interviewee six minutes on average to try to solve the Jeopardy problems. Our observations of students' attempts to solve the problem did not provide much information on how they would approach the problem. Thus, our data were mainly obtained from responses to probing questions.

The following themes emerged from analyzing the ways in which students approached these Jeopardy problems.

Converting numbers into symbols

In the first set of interviews, we used real numbers in the physics Jeopardy problems. All interviewees tried to convert the numerical representation to the physical symbol.

In expression (2), for instance only 11 out of 12 substituted $8.99\times10^{9}\,N\cdot m^{2}/C^{2}$ with the constant 'k', which often appears in the textbook.

When asked why they adopted this strategy, interviewees reported that they needed to convert the numbers into symbols to make sense of the equation. As one student remarked: "*They (physical symbols) are more straightforward …those numbers can be distracting.*"

To reduce the cognitive load of dealing with numbers and units while approaching this type of problem, in the second interview we used typical symbols representing physical quantities in the Jeopardy problems, such as expression (4)

$$\int_0^a \frac{\mu_0 .I.\dfrac{R}{\sqrt{s^2+R^2}}.ds}{4\pi.\left(s^2+R^2\right)} \qquad (4)$$

When asked to compare the Jeopardy problems that used symbols with those that used numbers, all of the interviewees said that they preferred the symbolic equation. One student commented, *"I do not think it [number] really makes sense to me, because if I see a number, then I just translate that to what variable it is… actually I like the variable method better, because I still need to write things down as variables."*

We found this observation to be rather interesting because when solving traditional end-of-chapter physics problems, in our previous research we have found that most students prefer numbers instead of symbols and they typically tend to substitute in numbers early in the problem solving process. Thus, Jeopardy problems appear to challenge the existing ways in which students approach problems and students appear to be changing their problem solving strategies in response to this challenge.

Using units to find the physical quantity

When provided with numbers and units, most interviewees tried to 'play' with the units to find the answer. For example, one student described her strategy as: *"I take all the units and convert them to find what variable they are looking for."*

This result was similar to the result above regarding the use of symbols in Jeopardy problems and converting them into a physical quantity with a unit.

Pattern matching without reasoning

Pattern matching appeared to be the most commonly used technique by our interviewees when solving Jeopardy problems. Students looked for the familiar terms that they could recognize and compared these with terms on the provided equation sheet.[1] One student described her/his strategy as *"I look for pieces of terms that I recognize μ_0, J (current density)…they will tell what kind of problem they are, I just tend to recognize forms, like derivative…"*

This pattern matching strategy sometimes helped interviewees find the right equation. For example, when interviewees noticed the numerical value of a symbol for μ_0 in the problem, they could narrow down their search on the equation sheet by just looking for the equation which involved μ_0. Using this method, one-half of the interviewees were able to find the right equation. However, when asked they were unable to explain why the given expression to the physical situation. For instance, one remarked, *"I do not know why those formulae work, I just use them."*

The other half of the interviewees were unable to use the pattern matching strategy to recognize the right formula. The reason was because when matching two expressions – one on the equation sheet and the other in the problem,, the interviewees tended to focus on a limited number of terms in the expressions instead of considering all of the terms. They paid more attention to the constants in the expression than the variable of integration. This tendency appeared to be a source of difficulty in deciding whether expression (5) referred to electrical field (E) or electrical potential (V) at a point, since all of the constants were the same for both cases.

$$\left[\int_{\infty}^{(3\times10^{-2}\,m)} (8.99\times10^{9}\,N\cdot m^{2}/C^{2})\frac{(5\times10^{-10}\,C)dr}{(3\times10^{-2}\,m)^{2}}\right] \qquad (5)$$

Students' problem solving strategies appeared to rely heavily on pattern matching, which may have helped them in some situations but were seldom adequate in helping them construct the physical situation represented by the expression.

Inability to interpret integration variable

When provided with an expression in symbolic form, we found that students had difficulties in interpreting the physical meaning of the variable of

[1] We gave interviewees an equation sheet because students were given an equation sheet during their EPII exams. The equation sheets we used were very similar to the ones given for the exams.

integration or using that variable to glean the geometry of the physical situation.

Students were provided expression (6) and asked to construct a physical situation corresponding to it. The physical situation that expression (6) corresponds to is the magnetic field due to a line of charge as evaluated using Biot-Savart's Law.

$$\int_0^a \frac{\mu_o . I . \dfrac{R}{\sqrt{s^2+R^2}} . ds}{4\pi\left(s^2+R^2\right)} \qquad (6)$$

One-half of the interviewees were unable to explain the meaning of 'ds' any further than to state that it was the variable of integration.

A similar situation occurred with expression (7).

$$\int_0^R \frac{J(r).(2\pi r dr)}{2\pi R} \qquad (7)$$

When asked to explain or draw $2\pi r dr$, few interviewees appeared to understand that $2\pi r dr$ represented an annulus of width 'dr' and radius '$2\pi r$' small ring shape. Two of the 12 students appeared to realize that it had something to do with the circular geometry of the situation; however, when asked to explain the situation more clearly, they appeared to be unclear and stated: *"…just the circle, that is what the integration means," "the circle dA (area) is always* $2\pi r dr$ *, although I do not know why."*

This result indicates that the students had difficulties understanding the physical significance of variables of integration such as ds or dr and could not use these as clues to decipher the problem situation. This indicates that students faced difficulties in deconstructing the expression provided in these Jeopardy problems.

Value of Jeopardy problems

Although interviewees generally agreed that Jeopardy problems were very hard to solve, most of them believed that solving Jeopardy problems would help them better understand physics concepts because, as one students remarked, *"if we break down the problem and find out each part and then figure out how they relate to some other parts, you can only truly understand something complicated if you break it down to each part and why it uses in different cases. For the back of chapter problems, you just manipulate formula."*

CONCLUSIONS

To address the research question posed at the beginning of this paper we conclude, based on results described above that students had difficulty deconstructing their provided calculus expression to create an equivalent physical situation.

Students tended to rely on ends-means analysis without invoking deeper conceptual understanding. When trying to construct an appropriate physical situation corresponding to a given Jeopardy expression, our interviewees tended to focus on limited numbers of constants rather than on the variable of the integration or differentiation to help them construct the physical scenario. They often used dimensional analysis and unit matching to find out the physical quantity that was being calculated in the expression. Students appeared to have difficulties in understanding what each element meant in the expression provided.

In spite of the fact that Jeopardy problems were deemed rather challenging by all of the students, they appeared to enjoy the challenge and believed that solving these problems was a useful learning experience. Thus, there may be some value in exploring the use of these problems in calculus-based physics to help students understand the physical meaning of mathematical representations.

REFERENCES

1. Mckeough, R.E., J. Lupart, and A. Marini, *Teaching For Transfer: Fostering Generalization In Learning.* 1995, Mahawah, Nj: Erlbaum.
2. Van Heuvelen, A., Maloney D., *Playing Physics Jeopardy*. American Journal of Physics, 1999. 67: p. 252-256.
3. Byrnes, J.P., *Cognitive Development and Learning In Instructional Contexts*. 1996, Boston, MA: Allyn and Bacon.
4. Rebello, N.S., et al., *Dynamic Transfer: A Perspective From Physics Education Research*, in *Transfer Of Learning From A Modern Multidisciplinary Perspective*, J.P. Mestre, Editor. 2005, Information Age Publishing Inc.: Greenwich, CT.
5. Newmann, D., Griffin. P., Cole, M., *The Construction Zone: Working For Cognitive Change In School*. 1989, New York: Cambridge University Press.
6. Cui, L., N.S. Rebello, and A. Bennett. *College Students' Transfer From Calculus to Physics*. In *2005 Physics Education Research Conference*. 2005. Salt Lake City.
7. Marton, F., *Phenomenography- A Research Approach To Investigating Different Understanding of Reality*. Journal of Thought, 1986. 21: P. 29-39.