Examining the necessity of problem diagrams using MOOC AB experiments

Zhongzhou Chen
Massachusetts Institute of Technology
77 Massachusetts Ave.
Cambridge, MA, 02139
617-324-2731
zchen22@mit.edu

Neset Demirci
Balıkesir Üniversitesi
Bigadiç Cd., 10145 Paşaköy
Balıkesir, Turkey
0.266.2412762
ndemirci@gmail.com

David Pritchard
Massachusetts Institute of Technology
77 Massachusetts Ave.
Cambridge, MA, 02139
617-253-6812
dpritch@mit.edu

ABSTRACT
Earlier research on problem solving suggested that including a diagram in a physics problem brings little, if any, benefit to students' problem solving success. In 6 AB experiments conducted in our MOOC, we tested the usefulness of problem diagram on 12 different physics problems, collecting over 8000 student responses in total. We found that including a problem diagram that contains no additional information very slightly improves the first attempt correct rate. On the other hand, in half of the cases, removing the diagram significantly increased the fraction of students who elected to draw their own diagram during problem solving. The results suggest that in contrast to conventional wisdom, the benefit of including a problem diagram rarely justifies the cost of creating one.

Keywords AB experiments, MOOC, problem diagrams.

1. INTRODUCTION
As instructors, we often feel obliged to accompany the problems we write with a figure or a diagram, even when all the necessary information is already included in the problem body. However in many cases, creating a "good looking" diagram or figure can be significantly time consuming and expensive. Therefore, it is a valuable question to ask whether a problem diagram does indeed help students solve problems more accurately or more quickly, and if so, does the benefit justify the cost of creating one?

Cognitive learning theories, such as dual coding hypothesis [7] and multimedia learning theories [6, 8] indirectly suggest, that diagrams can be potentially beneficial to problem solving. On the other hand, a series of recent experiments by Lin, Maris and Sigh[2–4]found that for the problems involved in their study, the accompanying diagrams have no detectable benefit for problem solving, and sometimes hurt performance by discouraging students to draw their own diagrams during problem solving.

Using the "split test" feature of the edX platform [1], this study addresses the following research questions in the context of a calculus based introductory mechanics course:

1. Do diagrams in general have an impact on students' problem solving performance (either percentage of correct answer or time spent on problem solving)? If so, to what extent?

2. Do diagrams change students' problem solving behavior, or more specifically, their decision to draw their own diagram?

2. MATERIALS AND METHODS

2.1 AB experiment on the edX platform
The edX platform allows the course creator to create controlled AB experiments by splitting the student population into two or more groups (called "partitions"), and presenting each group with a different version of content, such as a problem or a series of problems and html pages. Every student who tries to access the experimental course content for the first time is randomly assigned to one of the groups at the time of the access.

2.2 Experiment Design
A total of six experiments with identical design were implemented throughout the first eight units of the course. Each experiment involves two problems chosen from either the homework or the quiz section of a given unit, so the study involves twelve different problems in total. The problems were chosen from the first eight units of the course, covering kinematics, Newton's laws, circular motion, conservation of momentum, and conservation of energy.

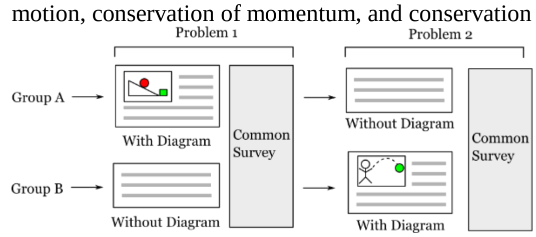

Figure 1: Experiment design. Each experiment consists of a pair of problems differing only in whether (DG) or not (NDG) they had a diagram. The same design is used for all 6 experiments conducted.

In each two-problem experiment, the student population was randomly partitioned into two groups: A and B (**Figure 1**). Group A saw the first problem in DG format and the second problem in NDG format. Group B saw the two problems in the same order, but the DG/NDG condition was reversed. The group assignment for each experiment is independent, reducing systematic bias.

Depending on when each experiment was released to students in the course, the number of students in each group ranged from ~480 (week 2) to ~180 (week 7).

The following survey question was asked after each problem:

When solving this problem, (check all that apply)

- ○ I drew one or more diagrams
- ○ I wrote down some equations
- ○ I did the problem entirely in my head
- ○ I used some other means to solve the problem

Only students who answered both the problem and the survey were included in the analysis.

3. RESULTS AND DISCUSSION

3.1 Results

We first look at the impact of including a diagram on the percentage of correct answer on students' first attempt. In most cases (see Fig 2 below) the presence or absence of a diagram has little impact on the difficulty of the problem itself. Only 3 out of 12 problems (P3, P4 and P8) showed a significant difference in difficulty between the two conditions ($p < 0.05, \chi^2 > 5$).

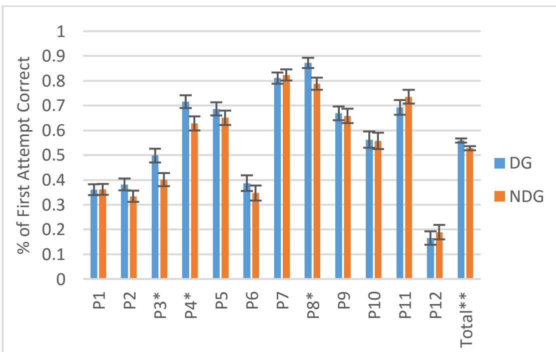

Figure 2: Percentage of first attempt correct for each problem. *Difference is significant at the 0.05 level. ** Difference is significant at the 0.01 level. (Chi-squared test)

Since we carefully balanced systematic bias in the population in our experiment design, it is meaningful to add up the data from all 12 problems and compare the overall success rate between the DG vs. NDG conditions (rightmost column in Fig 2). The overall correct rate under the DG condition is higher than that in the NDG condition by $3 \pm 0.8\,\%$. The difference, although small, is still statistically significant due to the large cumulative sample size (~ 3500 observations per condition, $p < 0.01, \chi^2 = 6.9$).

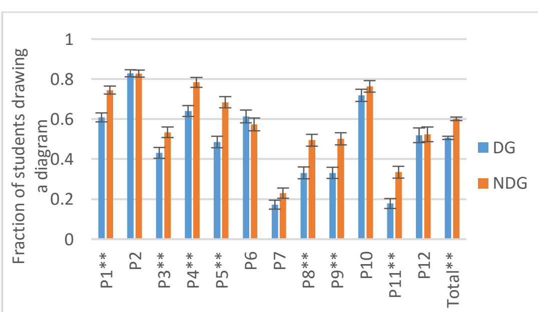

Figure 3: Percentage of students who drew a diagram solving each problem. *Difference is significant at the 0.05 level. ** Difference is significant at the 0.01 level. (Chi-squared test)

The presence/absence of a problem diagram impacts students' tendency to draw their own diagram as measured by the survey question. As shown in Figure 3, on 7 out of 12 problems, a significantly lower fraction of students ($p < 0.01, \chi^2 > 7$, Chi-square test) in the DG condition reported drawing their own diagram during problem solving than in the NDG condition. A noteworthy observation (Fig. 3) is the high variation in sensitivity of different problems to the DG/NDG condition. Combining the data across all 12 problems, students in the DG condition are 10% less likely to draw their own diagram than in the NDG condition ($p < 0.001, \chi^2 = 65$).

3.2 Discussion

Perhaps the most surprising observation of this study is how little students benefit from a problem diagram. Even with the large sample size provided by MOOC, significant difference between the two conditions are only observed for 3 out of 12 problems, with the largest difference at 10% and the overall difference at merely 3%.

Those results suggest that even though the benefits predicted by conventional wisdom and dual-coding hypothesis may still exist, the effect size might be small in an *in vivo* situation and only significant in the more extreme cases. For the majority of "normal" physics problems, our findings are consistent with previous studies [2–5] indicating that the benefit of a diagram is small.

In stark contrast to the correct rate, the decision to draw is very sensitive to the DG/NDG condition on 7 out of 12 problems: when the problem diagram is removed, students are 10% more likely to draw their own.

For instructors, the study suggests that for common physics problems of average difficulty, the benefit of adding a diagram may be too small to justify the resource and effort required to create it.

4. ACKNOWLEDGMENTS

Our thanks to Dr. Qian Zhou for helping on data analysis.

5. REFERENCES

[1] edX Documentation: Creating Content Experiments: *http://edx.readthedocs.org/projects/edx-partner-course-staff/en/latest/content_experiments/index.html*.

[2] Lin, S.-Y. et al. 2013. Student difficulties in translating between mathematical and graphical representations in introductory physics. 250, (2013), 250–253.

[3] Maries, A. and Singh, C. 2014. A good diagram is valuable despite the choice of a mathematical approach to problem solving. *2013 Physics Education Research Conference Proceedings*. (Feb. 2014), 31–34.

[4] Maries, A. and Singh, C. 2012. Should students be provided diagrams or asked to draw them while solving introductory physics problems? *AIP Conference Proceedings*. 1413, (2012), 263–266.

[5] Maries, A. and Singh, C. 2013. To use or not to use diagrams: The effect of drawing a diagram in solving introductory physics problems. *AIP Conference Proceedings*. 1513, 1 (2013), 282–285.

[6] Mayer, R.E. 2001. *Multimedia Learning*. Cambridge University Press.

[7] Paivio, A. 1986. *Mental representations: a dual coding approach*. Oxford University Press.

[8] Schnotz, W. 2002. Towards an Integrated View of Learning From Text and Visual Displays. *Educational Psychology*. 14, 1 (2002), 101–120.