

Preliminary Study of Impulse-Momentum Diagrams

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Abstract. In this paper we present a new representation to help students learn about momentum, impulse and conservation of momentum which we call an Impulse-Momentum Diagram. We include a description of this diagram as well as examples of how instructors can use them in the classroom. Next we present preliminary quantitative and qualitative data of a study we conducted where students used these representations. Our final analysis shows how students benefited from these representations.

Keywords: Multiple Representations, Impulse, Momentum, Diagrams.

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INTRODUCTION

Representations are a great tool to help students learn how to solve problems and understand physics concepts [1]. These representations can be content specific like free-body diagrams in areas of mechanics and electrostatics, or schematics for circuits. However, there are relatively few options to help students understand momentum.

Beyond the algebraic and pictorial representations for momentum, one option instructors have is momentum bar charts [2] which are similar to energy bar charts [3]. Momentum bar charts highlight key points such as the direction and conservation of momentum. In this paper we present a second and new option, Impulse-Momentum Diagrams (IMDs) created by Rosengrant. We describe these diagrams in the next section.

IMPULSE-MOMENTUM DIAGRAMS

Momentum is the product of a scalar quantity (mass) and vector quantity (velocity). Thus a representation for momentum must adhere to these two conditions. IMDs do this by combining motion diagrams with basic geometry. The key pieces of information utilized from motion diagrams are the direction and magnitude of the object's velocity. The longer the arrow, the faster the object moves. To modify this to represent momentum we need to

incorporate the object's mass. We accomplish this by making the thickness of the line correspond to the mass of the object. Thus the area of the rectangular portion of the arrow corresponds to the magnitude of the momentum. Figure 1 is an example IMD.

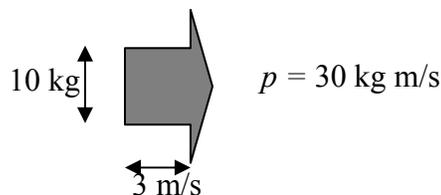


FIGURE 1. Example of an Impulse-Momentum Diagram.

If you choose to use an IMD to represent an impulse, then the length of the arrow represents the magnitude of force, the direction of the arrow represents the direction of the net force and the thickness of the arrow represents the length of time. In both cases the area of the rectangular portion of the arrow corresponds to the magnitude of the momentum. It may be beneficial to initially present IMDs on graph paper to help students visualize the representation. Another option is to eliminate the arrow head altogether and use only the rectangular portion of the arrow with two lines forming an arrow to show the direction of the object. To determine if IMDs are a beneficial representation for students and instructors, we conducted a preliminary study.

TABLE 1. Students' Answers to the Multiple Choice Questions (Correct Answers are Bolded)

Question & Group	# of "a" Responses	# of "b" Responses	# of "c" Responses	# of "d" Responses	# of "e" Responses
Q1 Mathematical Grp.	7	9	12	1	n.a.
Q1 IMDs Grp.	7	10	14	0	n.a.
Q2 Mathematical Grp.	4	5	0	8	12
Q2 IMDs Grp.	2	2	2	10	15
Q4 Mathematical Grp.	4	13	12	n.a.	n.a.
Q4 IMDs Grp.	8	14	9	n.a.	n.a.
Q6 Mathematical Grp.	8	2	6	6	6
Q6 IMDs Grp.	8	7	9	6	1

STUDY

This study was conducted during the Spring 2008 semester at Kennesaw State University. The students who participated in the study were from a first semester introductory algebra based physics course. Most students who took the course majored in biology or chemistry.

Course Setting

All 61 students (55% male, 45% female) were part of one lecture course taught by one of the authors. The class met twice a week in a traditionally designed lecture room with modern projection tools for a seventy five minutes lecture. Additionally, the class was divided into different lab sections taught by the same professor. Each lab section met once a week for a three hour lab and recitation session. The instructor taught the course using multiple techniques: lectures enhanced by technology and physics education research-inspired techniques such as peer instruction [4] and interactive lecture demonstrations [5].

Instruments / Participants

We conducted the study during one of the lab sessions in lieu of a lab. All of the students were required to complete the activities but were free not to let us use the data. All but one elected to participate.

All of the students received a study guide about momentum, impulse and conservation of momentum before receiving any formal in-class instruction on the topics. The text of the study guide was modified from sections 7.1, 7.2 and 7.4 of Hewitt's Conceptual Physics [6]. 29 students received a study guide with explanations and sample problems using only mathematical representations, which we will refer to as the mathematical group. The other 31 students received a study guide using only IMDs (no mathematics), which we will refer to as the IMD group. Both the verbal descriptions and the problems in the guides were almost identical to each other.

When the students finished reading the study guides, we gave them a seven question assignment sheet (Appendix). The assignment sheet contained conceptual questions from the multiple-choice Energy and Momentum Conceptual Survey [7] and numerical and pictorial questions. Upon completion of the assignment sheet we gave them the other study guide to read. When they finished this guide, they answered a survey. The survey questions were open-ended and Likert-scale that were based on questions from references 3 and 8.

Findings

We first analyzed the answers students gave on each of the conceptual questions (1, 2, 4, 6). The data is provided in Table 1. The results show that student performance in 3 out of the 4 questions is almost identical across both groups. Question 2 has a slight trend favoring the IMD group, however, a standard t-test shows the difference is not statistically significant. The only significant difference found between the groups involves the answers to question 6. More math students chose the incorrect answer e ($p=0.0356$). Though not significant, more IMD students chose the incorrect answer b ($p=0.0920$).

Next we analyzed the quantitative questions (5 & 7). The results are shown in Table 2. For both questions we used a standard t-test and found no statistical significant difference between the number of correct answers from each group. Question 7 shows a trend ($p=0.2028$) but again, it is not significant. What is interesting to note is that in the conceptual questions the IMD group did as well or better than the Math group for all questions. However, in the quantitative questions the groups were statistically identical.

TABLE 2. Number of Correct Responses to Quantitative Questions.

Question & Group	Number of Correct Answers
Q5 Mathematical Grp.	10
Q5 IMDs Grp.	13
Q7 Mathematical Grp.	17
Q7 IMDs Grp.	13

Next we analyzed the results of the survey (which came after they studied both guides). Our first open ended question was: *Did using the momentum – impulse arrows help you learn momentum concepts and solve momentum problems? Explain why they were or were not useful.* We broke the student answers into the following categories: A – helpful because its visual, B – helpful for another reason, C – prefer numbers or equations, D – not helpful, E – neutral. The results are shown in Figure 2. The y-axis in each figure represents the number of students in that category. We see that 58.3% of the students found the IMDs useful. About half of those students clearly stated the reason they found the diagrams helpful was because they are visual learners. However, 21.7% of the students did not find the diagrams useful. They gave reasons such as they were unfamiliar with the diagrams, thus making them difficult to use. Others said that they just prefer a basic picture. Some claimed that the problems were very easy to understand and that there was no need for the diagrams. The rest of the students (20%) were undecided. For example, one student said “I don’t think I fully understood them, I can see them being useful though.” Other comments are similar to this one.

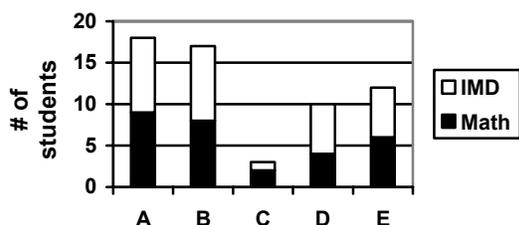


FIGURE 2. Results of Survey Question 1

Our second open-ended survey question was: *Did representing the momentum process in multiple ways help you learn concepts and solve momentum problems? Explain why they were or were not useful.* We categorized their answers into “Yes”, “No” and “Neutral” (Figure 3). We asked this question, partly to see how consistent students’ responses were with survey question 1. In this case 82.1% (compared to 58.3%) of the students found the IMDs to be useful.

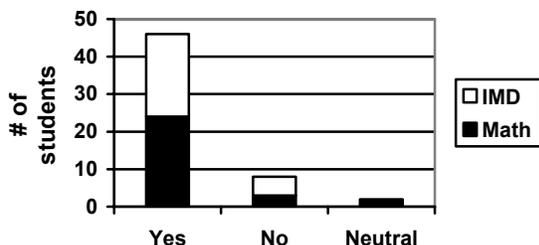


FIGURE 3. Results of Survey Question 2

Only 14.3% (compared to 21.7%) found the IMDs to be more confusing. One student stated: “Too many methods gets confusing to me. I usually end up with more than one answer.” Furthermore, some of the students in this category commented again that the problems were very easy and it is too much work to draw a picture for such basic situations. Four IMD students left the last 4 questions blank, thus we did not include them in the totals for those questions.

The third survey question was: *Which version would you initially have preferred to help you qualitatively and quantitatively understand momentum?* We asked this question to determine the students’ instructional preference. The results are in Figure 4. The number of students who wanted the “Math” version first is roughly the same among groups. Overall, more students prefer to see the Math version first. Interestingly, students in the IMD group seem to want the Math version first while student in the Math group are equally divided. One possible explanation is the IMD group was able to answer conceptual questions, but not the mathematical, thus they felt they needed that information first. The answers we placed in the “other” category were responses such as: “the written version helped me better” or “Qualitatively, [IMD] is the best because it gives more information to learn from including diagrams. Quantitatively [Math] explains the math concepts better.” Also, two students from the IMD group commented they should appear simultaneously.

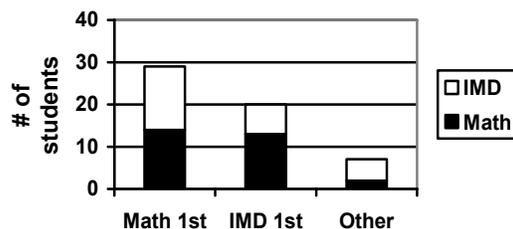


FIGURE 4. Results of Survey Question 3

Our final open-ended survey question was: *Do you feel the momentum-impulse diagrams furthered your understanding of momentum concepts? Explain your answer.* The answers are shown in Figure 5. 73.2% of the participants stated that they found IMDs to be beneficial. The 17.9% of the class who did not find them useful included reasons such as the situations being too simple, or that they didn’t fully understand the diagrams. The same arguments were used from responses in the yes and no category. Students could see the potential for the diagrams but argued that they didn’t fully understand them yet, or that they preferred to have the IMDs along with the equations.

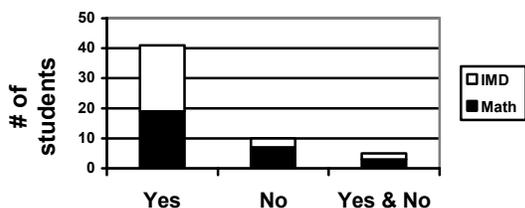


FIGURE 5. Results of Survey Question 4.

DISCUSSION

Results from the open-ended survey indicate that the students reacted favorably to the IMDs. The students found the diagrams useful because they believe they are visual learners. The students who did not find them useful stated that they preferred equations or that they were confused by the diagrams. This might suggest that they would react differently if they had more instruction about the diagrams, perhaps simultaneously with the mathematical descriptions.

The quantitative results from this limited study suggest that neither group performed better. However, the data hints to differences in performance with conceptual questions. We believe, based upon the data that the IMD can be a useful tool to use in the classroom. We know that this data is preliminary, but the results warrant more research on this matter.

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APPENDIX

1. Two identical bullets are fired horizontally with identical speeds v_0 at two blocks of equal mass. The blocks rest on a perfectly frictionless horizontal surface and are made of hard steel and soft wood respectively. One bullet bounces elastically off the steel block. The other bullet becomes embedded inside the wood block. Which block has the greater velocity to the right? [Figure given]

- Steel block
- Wooden block
- They are the same
- Not enough info.

2. A motorcycle and a truck are both moving in the same direction in adjacent lanes on a highway. At a particular instant, the speed of the motorcycle is four times as large as the speed of the truck v . At that instant, the motorcycle is accelerating forward while the truck is moving at a constant velocity. Which one of the following statements best describes which vehicle has a larger momentum at that instant?

- the truck because it has a larger mass
- the motorcycle because it is moving faster
- the motorcycle because it has an acceleration
- reasons b and c
- not enough information

3. Draw a picture of question 2

4. The brakes of your bicycle failed and you must choose between slamming into either a haystack or a concrete wall. Which one of the following statements best justifies why hitting a haystack is a wiser choice than hitting a concrete wall?

- The haystack gives you a smaller impulse than the concrete wall.
- The haystack changes your momentum over a longer time.
- Your change in momentum is smaller if you hit the haystack than if you hit the concrete wall.

5. A 1000 kg compact car traveling at 25 m/s due east collides with a 1500 kg truck that is parked. The two vehicles stick together. What is the velocity of the two vehicles after the collision?

6. You and your friend are both standing on a horizontal frictionless surface. To get your friend's attention, you throw a ball due west at your friend as shown below. The ball bounces elastically off your friend's back. Which one of the following statements is true about this situation? (Figure given to students)

- Your friend will remain stationary because the ball bounces elastically and does not impart its momentum to her.
- Your friend will remain stationary due to conservation of linear momentum.
- You will remain stationary after you throw the ball due to conservation of linear momentum.
- You will move east after you throw the ball due to conservation of linear momentum.
- None of these statements are true.

7. A 1000 kg rocket car is sitting at rest in a very flat portion of the Nevada desert. The rockets are turned on for 5 seconds and exert a force of 15000 Newton's on the car. How fast is the car moving at the end of the 5 seconds? Be sure to include a picture.

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