

# Evaluating an interactive lecture demonstration implementation in a lab setting: An example from a collisions and momentum learning activity



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## Abstract

The results of an implementation of the *Interactive Lecture Demonstrations* (ILD) strategy developed by Thornton & Sokoloff [1] are presented. The strategy guides the students through prediction, observation, registration, and discussion steps. The sample consists of 166 students split in two groups: the control group (CG) of 66 students divided in 17 work teams and the experimental group (EG) of 65 students, formed by 13 work teams. The implementation was carried out in an introductory physics course corresponding to Newtonian mechanics as part of the lab sessions at a large private Mexican university. The covered topic was collisions and linear momentum and the collected data corresponds to the 13<sup>th</sup> week of classes when the topic was studied in the classroom. The goal was to identify the feasibility and success of the implementation in a learning setting where other active learning strategies have been used. Among the main findings it is reported a better conceptual evaluation of the students along with a positive attitude shown by the lab assistants. Besides that, a change in the students' reasoning when comparing their prediction and observation registered was found.

**Keywords:** ILD, Active learning, Momentum, Collisions, Laboratory.

## Resumen

Se presentan los resultados de la implementación de una actividad de la estrategia *Demostraciones Interactivas de Lectura* (ILD) desarrollada por Thornton y Sokoloff [1]. La estrategia guía a los estudiantes a través de los pasos de predicción, observación, registro de datos y discusión. La muestra consta de 166 estudiantes divididos en dos grupos: el grupo de control (GC) de 66 alumnos agrupados en 17 equipos de trabajo y el grupo experimental (GE) de 65 estudiantes, formado por 13 equipos de trabajo. La implementación se llevó a cabo como parte de las sesiones de laboratorio de un curso introductorio de mecánica newtoniana, en una universidad privada de México. El tema estudiado en la sesión fue el de colisiones y cantidad de movimiento. Los datos recolectados corresponden a la 13<sup>a</sup> semana de clases cuando el tema se estudia en el aula. El objetivo era determinar la viabilidad y el éxito de la implementación en un entorno de aprendizaje donde otras estrategias de aprendizaje activo se han utilizado. Entre las principales conclusiones se tienen una mejor evaluación conceptual de los alumnos y una actitud positiva mostrada por los asistentes de laboratorio. Asimismo, se observó un cambio en el razonamiento de los estudiantes al comparar las predicciones y observaciones que registraron en sus hojas de trabajo.

**Palabras clave:** Aprendizaje activo, impulso, colisiones, laboratorio.

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## I. INTRODUCTION

Students' conceptual difficulties in science have been object of research on specific topics, including momentum and energy conservation [2, 3]. In order to confront those difficulties in the classroom setting some learning strategies have been developed based on research [4]. Nowadays, as part of that change, some strategies like *Tutorials for Introductory Physics* [5] are being used on a private university in the north of Mexico.

In order to explore different strategies, it was decided to implement an *Interactive Lecture Demonstrations* (ILD) activity [6] in a complementary lab session of an introductory physics course. The chosen topic was collisions and momentum. The aim was to identify feasibility and success of the implementation of this learning activity in a setting where other types of active learning strategies have been used. The scope includes a measurement of the achieved learning with the ILD activity compared to groups carrying out the traditional lab activity. Limitations included time constraints, available lab

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equipment and resources, and lack of experience implementing an ILD activity.

In the following sections, the theoretical ideas underlying the ILD strategy and a brief summary on findings of research on conceptual understanding of momentum are presented. Then, the method that guided the assessment of learning and implementation is exposed and, finally, results and conclusions are discussed.

## II. THEORETICAL FRAMEWORK

### A. Interactive Lecture Demonstrations

ILD strategy emerges from establishing an effective learning environment to take advantage of lecture time in introductory courses at some American universities [1, 7]. After a few years of testing, a procedure based on research was developed for ILD. Making learning process interesting for the students and therefore turning a lecture into a more active learning environment is the main objective. The strategy is founded on the physics teaching goal of translating from a passive to a more active learning environment [4], promoting that the students build their own knowledge and that the instructor acts as a guide in the learning process enforcing knowledge exchange and collaborative learning [1, 8]. ILD strategy also relies on the effective use of experiments during the learning process to imitate real-science process of understanding, proposing hypothesis and testing them, thus confronting naïve ideas with experimental facts and developing them into more sophisticated science-congruent concepts [9]. Experiment demonstrations are held in front of the classroom observing specific procedure steps to obtain predictions, observations and results while fomenting discussion.

The ILD procedure consists of a specific eight-steps cycle: i) the instructor describes and presents the experiment without measured data; ii) students write down their personal predictions; iii) students discuss their predictions with peers; iv) students write down their conclusions; v) the instructor elicits common predictions, vi) the experiment is carried out with measured data suitably displayed; vii) a class discussion is held and students write down observations and conclusions on results sheets, and viii) the instructor discusses analogous physical situations. The ideas underlying this strategy are similar to the elicit-confront-solve cycle common to other active learning strategies [5], strongly supported on peer and instructor-student discussions.

Favorable results have been found from ILD implementation. It has been reported up to an 80% of conceptual understanding improvement related to the learned topic [7, 10]. On the other hand, the use of this strategy is considered to improve students' learning by promoting student discussion and an adequate use of lab equipment [1, 7, 8].

### B. Students understanding of collisions and momentum

Research on cognitive difficulties in mechanics has been extensive, especially on kinematics and forces. However, research on students' understanding of momentum has usually been focused either in one aspect –like the understanding and application of the impulse-momentum theorem [3]– or in the proposal of learning activities [11]. Graham and Berry [2] have formulated a development model of the student's understanding of momentum; it consists of four levels of conceptual understanding that go from inexistent (level 0) to a “very comprehensive” (level 3) as stated by the authors. This model offers a reasonable frame of reference to analyze conceptual understanding and conceptual change when learning momentum.

To reach a level, students are required to success at all the lower levels. Students who do not achieve the requirements for level 1 are assigned to level 0 and their understanding of the topic is considered to be very confused or inexistent. Level 1 defines a somewhat naïve or intuitive understanding focused in a scalar reasoning; it requires the student to be able to: i) recognize the product of mass and speed as an important quantity and ii) to compare the momenta of different objects moving in the same direction. Level 2 requires the students to be able to: i) recognize momentum as a vector quantity, ii) define operationally momentum as the product of mass and velocity, iii) model simple situation in which the mass of a moving body changes, iv) understand and apply the principle of conservation of momentum in one-dimensional situations, and v) understand and apply the impulse-momentum theorem in one-dimensional situations. Finally, a level 3 student should be able to: i) understand and apply the principle of momentum conservation and ii) understand and apply the impulse-momentum theorem, both in two-dimensional situations.

## III. METHODOLOGY

### A. Sample and context

The implementation was held at Tecnológico de Monterrey, a private university in the north of Mexico. The subjects were 131 freshmen enrolled in a Newtonian mechanics course (Physics I): 66 of these students (divided in 17 work teams) were part of the control group (CG) while the other 65 (13 work teams) formed the experimental group (EG). Physics I is taught in 45 hours of classroom sessions and six lab sessions distributed in a 15-weeks period. Typical classroom strategies are lectures, recipe-like experiments, collaborative work and the Physics Education Group's *Tutorials* [5].

The context of the study was the last lab session, carried out during the 13<sup>th</sup> week of the semester. At the moment, the topic was momentum and collisions. The concepts were introduced to the students and the Tutorial *Changes in energy and momentum* [12] was completed in classroom sessions during the 12<sup>th</sup> week in the semester. During the

13th week, besides the lab activity, the topic of momentum and collisions and the Tutorial *Conservation of momentum in one dimension* [13] were completed in classroom.

Lab sessions are held in two-hours sessions every two weeks. Students are distributed in four work teams of four to six members each team. They complete the proposed activity and, at the end of the session, they answer a short test. The sample consisted of 10 lab groups: five in the control group and the other five in the experimental group.

The proposed activity for the momentum and collisions lab session consisted of recipe-like experiments involving collisions between carts on low-friction tracks. The students were required to analyze the events by using motion sensors and by applying concepts and ideas learned during classroom sessions –like momentum and energy conservation– to solve for unknowns –like final velocities. The control group completed this activity.

The experimental group completed the equivalent ILD activity: *Momentum* [6]. Besides the activity and the strategy required by it, the dynamics of lab sessions was held as usual: students were distributed in 4 work teams and the same short test as the control group was given at the end of the session. During this ILD activity, six different experiments were carried out, each one presented in the eight-steps cycle as proposed by Sokoloff and Thornton [1, 8].

## B. Method and measurement tools

Learning was assessed in two different ways: i) by comparing the predictions sheets to the results sheets of the experimental group work teams, and ii) by grading the short test given at the end of the lab session. With respect to the comparison between the predictions sheets and the results sheets, the main concept for each demonstration was identified. Then, conceptual change between predictions and results was analyzed and frequencies of success were computed. For this analysis, only 12 of the 13 work teams handed in both the predictions sheets and the team's results sheets.

The short test given at the end of the lab session was written by the laboratory coordinating instructor and was the same for all the lab groups. It consisted of two free-response questions. The responses given by the students were analyzed and classified, and frequencies were computed for each type of response. These frequencies were compared between control group and experimental group.

To assess the implementation, a survey consisting of free-response questions and Likert-scale assessments was given to the five lab assistants of the lab groups that made up the experimental group. Lab assistants are junior and senior teaching assistants that teach at least two lab groups. Therefore, surveyed assistants had the experience of having assisted both the ILD and the recipe-like activity implementations.

## IV. RESULTS

### A. Predictions and results sheets comparison

Demonstration 1 consists of a free falling rubber ball. It aims for the recognition of the appropriate physical system under analysis in which the principle of momentum conservation applies. In their predictions, none of the teams was able to recognize the system consisting of the Earth and the ball as the physical system in which momentum is conserved. Moreover, they tried to describe different experiments in which the ball's velocity did not change – usually, the terminal velocity case. After observation and discussion, 10 of the 12 teams correctly concluded that momentum was conserved in the Earth-ball system.

Demonstration 2 focuses on the momentum change of a bouncing rubber ball. The main concept is the vector definition of velocity and, thus, of momentum. All the work teams predicted no change in momentum arguing that speeds before and after the bouncing were equal. After class discussion, eight teams wrote down that momentum did change explaining that velocity's direction did.

Demonstration 3 is about an elastic collision; the emphasis lies on the sketch of forces acting on each colliding object while they are in contact with each other. The concept that underlies this exercise is Newton's third law action-reaction pair of forces and its relation to the choice of the physical system in which momentum conserves. Six teams gave correct predictions, and after observation and discussion 10 teams wrote down correct responses on the results sheets.

Demonstration 6 emphasizes the importance of a null net force on the system in order to apply the principle of momentum conservation. In this experiment, a cart is made to collide with a wall. Students are expected to identify that the floor exerts a force on the wall so it does not move and momentum is not conserved in the cart-wall system. None of the teams predicted the existence of this external force on the free-body diagrams. After observation and discussion, 8 teams sketched it on their results sheets.

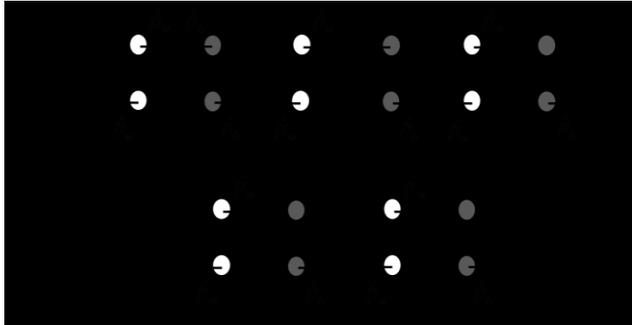
Results for demonstrations 4 and 5 are not presented since they are very similar to demonstration 3 and not all the lab groups completed them because of time restrictions. Table I summarizes the results for this analysis.

**TABLE I.** Frequencies of correct responses to predictions and results sheets (EG, N=12).

| Demonstration            | Correct responses |         |
|--------------------------|-------------------|---------|
|                          | Predictions       | Results |
| 1. Falling ball          | 0%                | 83%     |
| 2. Bouncing ball         | 0%                | 67%     |
| 3. 1D elastic collision  | 50%               | 83%     |
| 6. Collision with a wall | 0%                | 67%     |

**B. Short test**

The short test was given at the end of the lab session; it consisted of two questions about an imaginary experiment. An elastic collision between two billiard balls that travel on collinear paths (one-dimensional collision) is described and the students are asked to sketch: i) momentum vectors before and after the collision (question 1), and ii) free-body diagrams while the balls are in contact with each other (question 2). For each question, the types of responses were classified.



**FIGURE 1.** Classification of responses given to question 1.

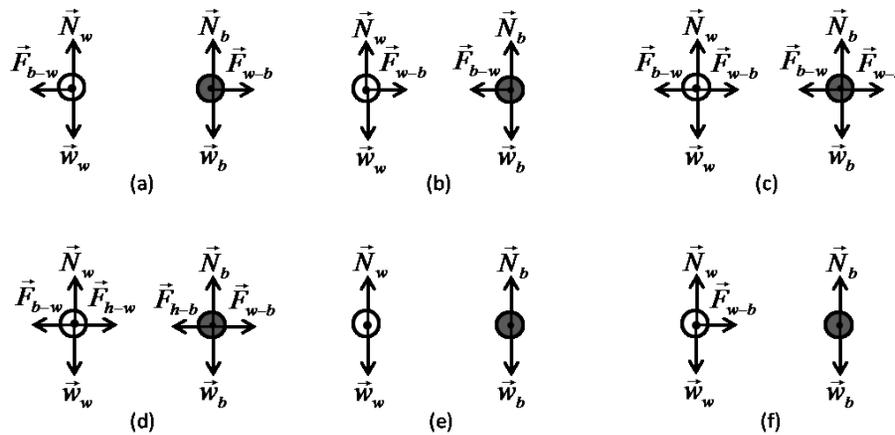
To answer correctly question 1, an understanding of the vector nature of momentum and of the principle of

conservation are needed. Fig. 1 shows the five types of responses given for question 1. From this set of answers, only answer (A) was identified as correct. In general, the other types of answers are not congruent with the principle of energy conservation required in an elastic collision. Frequencies are shown in Table II.

**TABLE II.** Frequencies of responses to question 1.

| Type of response | EG (N=13) | CG (N=17) |
|------------------|-----------|-----------|
| (A)              | 92%       | 70%       |
| (B)              | 0%        | 6%        |
| (C)              | 0%        | 6%        |
| (D)              | 0%        | 12%       |
| (E)              | 0%        | 6%        |
| Other            | 8%        | 0%        |

For question 2, the student should understand the concept of action-reaction pairs of forces and the meaning of free-body diagrams. The answers given by the work teams were classified in six different types; Fig. 2 presents them and their frequencies are given in Table III. Sketch (a) in Fig. 2 is the correct response. A common source of error in alternative sketches lies on the misconception that free-body diagrams includes forces exerted by the object under analysis.



**FIGURE 2.** The six different types of responses given to question 2.  $\vec{N}$  stands for the normal force exerted by the billiard table;  $\vec{w}$  is the ball's weight;  $\vec{F}$  is a contact force; and subscripts  $w$ ,  $b$  and  $h$  mean *white ball*, *black ball* and *hand*, respectively.

**TABLE III.** Frequencies of responses to question 2.

| Type of response | EG (N=13) | CG (N=17) |
|------------------|-----------|-----------|
| (a)              | 77%       | 35%       |
| (b)              | 0%        | 23%       |
| (c)              | 15%       | 18%       |
| (d)              | 0%        | 6%        |
| (e)              | 0%        | 6%        |
| (f)              | 0%        | 6%        |
| Other            | 8%        | 6%        |

**C. Survey**

To assess the implementation of the ILD activity a survey was given to the lab assistants. It consisted of yes/no questions complemented by free response questions, and of statements graded in a 1 through 5 points Likert scale, meaning *strongly disagree* and *strongly agree*, respectively. The five assessed areas were: i) efficient use of time, ii) suitability of the workspace and equipment, iii) comparison

between control group and experimental group performances, iv) engagement of students in discussion, and v) personal opinions and recommendations of surveyed assistants.

Table IV presents means and modes for the Likert scale statements. These statements assess the efficacy of the ILD activity to engage students in discussion and compare the effectiveness of using lab equipment between experimental and control group implementations. Likert values given to all the statements oscillated between 4 and 5, the two desired values. Also, all surveyed assistants thought positively of the ILD activity. By answering the yes/no questions, they all stated that time was spent efficiently, that the workspace was suitable and that they did notice differences in students' attitudes and confidence when answering the short test. They recommended implementing the ILD activity in future semesters.

**TABLE IV.** Means and modes for the Likert scale statements. 1 stands for *strongly disagree* and 5 stands for *strongly agree*.

| Statement   | Mean | Mode |
|---|------|------|
| The ILD activity promoted peer discussion.  | 4.8  | 5    |
| The ILD activity promoted peer discussion more than the recipe-like experiment.                                 | 4.6  | 5    |
| The ILD activity promoted discussion among the lab assistant and students more than the recipe-like experiment. | 4.4  | 4    |
| Lab equipment is better used in the ILD activity than in the recipe-like experiment.                            | 4.4  | 4    |

Even though not all lab groups had enough time to carry out all the 6 demonstrations, all the lab assistants believed that time was efficiently spent. Lab instructors also expressed that the use of lab equipment was appropriate to promote an integral observation of the experiments and to present in a clear and straightforward manner experiment features as the conservation of momentum. They also claimed to have observed differences in the performances of the control and the experimental groups: the experimental group expressed less doubts and answered in less time the short test at the end of the lab session.

#### IV. DISCUSSION

The implemented ILD activity is based only on demonstrations of one-dimensional collisions. Because of this, it aims at promoting conceptual learning equivalent to level 2 described by Graham and Berry [2] (and presented in section II of this paper).

The ILD activity effectively points out the vector nature of momentum since demonstration 2 promotes a change in 67% of the responses. With respect to the applicability of the principle of momentum conservation, demonstrations 1 and 6 emphasize the suitable choice of the physical system under analysis. Demonstration 1 promotes that 83% of the work teams recognize the physical system in which

momentum is conserved and demonstration 6 guides 67% of the responses to establish a relation between the existence of an external force to the system and the non-applicability of the principle of momentum conservation. Moreover, this kind of conclusions reaffirms the understanding of the impulse-momentum theorem, which is one of the hardest concepts to learn [3, 11]. Other important concepts promoted by the ILD activity are the action-reaction pair of forces and the use of free-body diagrams. Demonstrations 2 through 6 ask for free-body diagrams of the colliding objects while touching each other. In the predictions sheets, only half of the work teams identified correctly the forces involved in the collisions, but after discussion 83% of the responses were correct. This means a 67% normalized gain.

These ideas are supported by the results from the short test analysis. 92% of the work teams in the experimental group answered correctly the question about change in momentum vectors after an elastic collision –question 1–, while in the control group only 70% of the teams did so. With respect to the understanding of action-reaction pairs of forces and the use of free-body diagrams, 77% of the experimental group answered correctly question 2, while only 35% of the control group did. Moreover, the control group's set of alternative answers was larger than that of the experimental group, meaning that the ILD activity is effective eradicating misconceptions. This comparison of responses given by the experimental and the control groups to the short test points out that ILD activity promotes better understanding of the principle of momentum conservation, the concept of action-reaction pairs of forces and the use of free-body diagrams.

Besides these results, the lab assistants' answers and comments to the survey uniformly express positive opinions towards the implementation of the ILD activity. In general, they pointed out that peer discussion and class discussion was promoted and that the use of lab equipment facilitated a complete observation of the demonstrations making the presentation clear and straightforward. The lab assistants claimed to have observed that the students' attitudes and confidence toward the topic was better in the experimental group than in the control group. A lab assistant expressed that in the control group, students tended to focus only on one colliding object while the students that carried out the ILD activity "seemed to have a more inclusive, complete understanding of the phenomenon, a global view of it" by considering both colliding objects in their analyses.

#### V. CONCLUSION

From the positive results, we conclude that the ILD activity promotes effectively the conceptual understanding of momentum up to Graham and Berry's level 2. The conceptual change achieved from predictions to results after observation and discussion are around 70%-80%, similar to results reported in the literature [7, 10]. These conclusions and the coincident opinion of surveyed lab

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assistants aim at the recommendation of implementing the  
ILD strategy even in a lab setting. Moreover, the proposed  
analysis to assess learning showed valuable information  
that feedback the instructor about the conceptual learning  
and conceptual state of his/her students.

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## REFERENCES

- [1] Sokoloff, D. R. and Thornton, R. K., *Using Interactive Lecture Demonstrations to create and active learning environment*, The Physics Teacher **35**, 340-347 (1997).  
[2] Graham, T. and Berry, J., *A hierarchical model of the development of student understanding of momentum*, International Journal of Science Education **18**, 75-89 (1996).  
[3] Lawson, R. A. and McDermott, L. C., *Student understanding of the work-energy and impulse-momentum theorems*, American Journal of Physics **55**, 811-817 (1987).  
[4] Redish, E., *Teaching Physics with the Physics Suite*, (Wiley, USA, 2003).

- [5] McDermott, L. C., Shaffer, P. S. and the Physics Education Group, *Tutorials in Introductory Physics*, (Prentice Hall, USA, 2001).  
[6] Sokoloff, D. R. and Thornton, R. K., *Interactive Lecture Demonstrations*, (Wiley, USA, 2004), p. 117-128.  
[7] Thornton, R. K. and Sokoloff, D. R., *Assessing student learning of Newton's laws: The force and motion conceptual evaluation and the evaluation of active learning laboratory and lecture curricula*, American Journal of Physics **66**, 338-352 (1998).  
[8] Sokoloff, D. R. and Thornton, R. K., *Interactive Lecture Demonstrations*, (Wiley, USA, 2004), p. 1-13.  
[9] Etkina, E., Van Heuvelen, A., Brookes, D. T. & Mills, D., *Role of experiments in physics instruction - A process approach*, The Physics Teacher **40**, 351-355 (2002).  
[10] Sharma, M. D., Johnston, I. D., Johnston, H., Varvell, K., Robertson, G., Hopkins, A., Stewart, C., Cooper, I. and Thornton, R., *Use of interactive lecture demonstrations: A ten year study*, Physical Review Special Topics – PER **6**, 020119-1 to 020119-9 (2010).  
[11] Wyrembeck, E. P., *Using a force plate to correct students misconceptions*, The Physics Teacher **43**, 384-387 (2005).  
[12] McDermott, L. C., Shaffer, P. S. and the Physics Education Group, *Tutorials in Introductory Physics*, (Prentice Hall, USA, 2001), p. 43-48.  
[13] McDermott, L. C., Shaffer, P. S. and the Physics Education Group, *Tutorials in Introductory Physics*, (Prentice Hall, USA, 2001), p. 49-52.