

Transfer of learning from classical mechanics to electricity and magnetism. Part 2

Transferencia de conocimientos de mecánica clásica a electricidad y magnetismo. Parte 2

**Sergio Flores García, María D. Gonzalez Quezada,
Juan E. Chávez Pierce,
Natividad Nieto Saldaña, Esperanza Ibarra Estrada, María
Guadalupe Castro, Víctor Carrillo Saucedo*

ABSTRACT

The positive results in the first part of this investigation allowed us to use our *escalator* and *transfer* diagrams as effective tools to analyze the degree to which the exposure to the underlying ideas in a new context help to solidify the concepts first introduced in mechanics and the degree to which students have *transferred* their understanding of mechanics into analogous concepts in Electricity and Magnetism. In this article we will present the results of the analysis of the students' responses to the Mechanics and Electrostatics Assessment Tool (MEAT) using as measurement tools the escalator and transfer diagrams.

Keywords: Physics, electrostatics, Newtonian mechanics, knowledge of transfer

RESUMEN

Los resultados positivos en la primera parte de nuestra investigación nos permiten el uso de los diagramas *escalador* y de *transferencia* como herramientas efectivas para el análisis del grado en el que la exposición a las ideas subyacentes en un contexto nuevo ayudan a solidificar los conceptos que fueron previamente introducidos en los cursos de mecánica clásica y el grado en el cual los estudiantes transfieren su entendimiento de mecánica clásica a conceptos análogos en Electricidad y Magnetismo. En este artículo, presentaremos los resultados del análisis de las respuestas de los estudiantes al instrumento de diagnóstico Mechanics and Electrostatics Assessment Tool (MEAT) usando los diagramas escaladores y de transferencia como herramientas.

PACS: 01.40.-d; 41.20.Cv; 45.20.D-; 01.30.Ib

Palabras clave: La física, la electrostática, la mecánica newtoniana, la transferencia de conocimiento

Fecha de aceptación: 22.10.2015

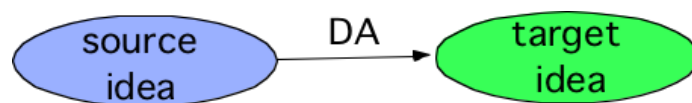
Aprobado: 20.11.2015

* Universidad Autónoma de Ciudad Juárez, seflores@uacj.mx

Introduction

In the first part of this investigation we found that most of the students answering correctly in the mechanics context as in the electrostatics context used the same reasoning, allowing us to assume that they were transferring a previous knowledge in a new context. Similarly, the inconsistency in the explanations that students provided when they answered correctly in a context and incorrectly in a new context, gave us the confidence to state that students do not see any connection between the two contexts (Gonzalez, 2013). Using these results, we feel free to use the *transfer* diagrams as a tool to measure the degree of transfer from mechanics to electrostatics. Moreover, in the preliminary study that we refer in the first part of this article, students showed an improvement from 75% in the pre-test to 82% in the post-test when we used the *escalator* diagrams.

In this article, we analyzed the students' responses to the Mechanics and Electrostatics Assessment Tool (MEAT) using the transfer and the escalator diagrams. Force concepts, Newtonian mechanics, and energy conservation are topics of introductory physics courses. They are the first contact that students have with physics and where students often show conceptual understanding difficulties and misconceptions, as Flores (2006) states in his Ph. D. dissertation. We relate the use of these difficulties and misconceptions on these topics with the difficulty to transfer previous knowledge between different contexts. From the different approaches to measure transfer, we chose targeted transfer (Carrillo, Flores y Gonzalez, 2014) where the source idea is the mechanics context and the target idea is the E&M context, as shown in Figure 1.



Figure

1 Targeted transfer scheme.

In a *targeted transfer* investigation there is a specific analogy that has been made between source and target by the investigator, and the test is a measure of the degree to which the student is able to replicate the investigator's analog reasoning. In the past few decades, some education researchers have begun to wonder whether the targeted transfer really tells us much. After all, despite consistent reports of lack of transfer, people still manage to learn things, which suggests they are somehow taking things they already

know and applying them to new situations. It could be that the constraint imposed by these studies – that the transfer by the student match the transfer path imagined by the instructor or by the investigator – is artificial and is inconsistent with how learning actually takes place.

In the book *Transfer on Trial*, Detterman (1993) state: “First, most studies fail to find transfer. Second, those studies claiming to find transfer can only be said to have found transfer by the most generous of criteria...”

The cause for failures to find students’ transfer of learning evidences could be that the investigators are looking for analogies they previously found between the source and the target. They are not allowing students to generate their own analogies. Atkins (2004) shows a discussion among several undergraduate students and the instructor in a conceptual physics course about static electricity in conductors and in insulators. Students spontaneously made analogies between the motion of electrons in metal and ice-skating. One analogy, among other generated analogies in this discussion, was:

“...I don’t agree with you saying that Styrofoam is more dense I think it’s less dense. And so that’s why the charges get caught up in it. ‘Cause it’s like –like cotton.’ And the pan, the pan is more dense and so they are able to slide across it like they can ice skate across it easier...”

Based on their evidence, Atkins (2004) states:

“generating analogies should be an important part of the science classroom -not as a tool for acquiring content knowledge but as a goal of a science education”

The last statement is in accordance with the research done by Schwartz, Bransford and Sears (2005), where they describe efficiency and innovation as two dimensions of learning and transfer. To provide students opportunities to innovate together with the skills and knowledge that efficiency represents could lead to an optimal adaptive expertise.

In this article, we will present the degree of transfer that students in four different populations showed through the escalator and transfer diagrams. Together with the results, we will talk about the common difficulties and misconceptions that physics education researchers have found previously that match with our findings in this investigation.

Population

New Mexico State University is our primary source of data. We selected four groups with different characteristics described below.

Group AC: An algebra based course with a strong emphasis on conceptual understanding $N = 143$.

Group CC: A calculus-based course with a strong emphasis on conceptual understanding $N = 55$.

Group CT: A calculus based course with primarily traditional instruction $N = 40$.

Group CCP: A calculus based course with emphasis on conceptual understanding where the students were primarily physics majors $N = 33$.

Targeted transfer about Force concepts

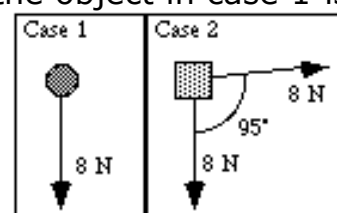
Net force

A pair of questions requiring students to compare the magnitude of the net force in two different situations was included in the MEAT (Figure 2). In a previous investigation, Flores, Kanim & Kautz (2004) used these questions to investigate how students understand vector superposition in electrostatics, and to determine whether instruction on vector superposition improves student understanding of net force. Kanim (1999) found that students tend to add vectors as scalars and to associate vector magnitudes with components in only one direction. The reasoning behind these answers could be related with the angle at which the two forces are acting on the object and the two charges are acting on the $+Q_0$ charge. It seems that students think that the sum of two forces at angles less than 90 degrees is less than only one force acting. This belief would correspond to the students' tendency to associate vector magnitudes with components in only one direction that Kanim (1999) found in his previous investigation.

Shown at right are free-body diagrams for 2 different objects. Which of the following statements is true?

(a) The magnitude of the net force on the object in case 1 is *less than* the magnitude of the net force on the object in case 2.

(b) The magnitude of the net force on the object in case 1 is *greater than* the magnitude of the net force on the object in



case 2.

(c) The magnitude of the net force on the object in case 1 is *equal* to the magnitude of the net force on the object in case 2.

(d) The magnitude of the net force on the objects *cannot be compared* unless we know the masses of the objects.

Which of the following statements is true?

(a) The force on $+Q_o$ in case A is *greater than* the force on $+Q_o$ in case B.

(b) The force on $+Q_o$ in case A is *equal to* the force on $+Q_o$ in case B.

(c) The force on $+Q_o$ in case A is *less than* the force on $+Q_o$ in case B.

(d) *There is not enough information given to compare the force on $+Q_o$ in the two cases.*

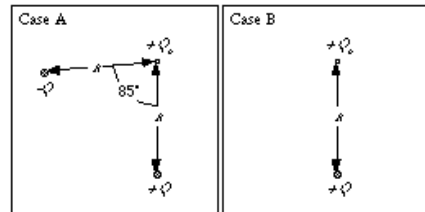


Figure 2 Pair of questions for the net force question

Gain in the mechanics context

Figure 3 shows the students' performance for this question in the mechanics context on pre and post-tests. Around 70% of students in the three Calculus groups (CC, CT, and CCP) answered correctly on both the pretest and the post-test. The number of students in the algebra group (AC) answering incorrectly and correctly is about the same, predominating the number of students answering incorrectly.

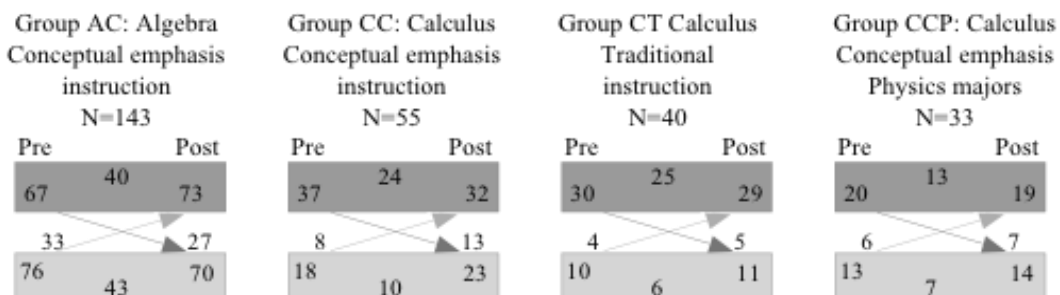


Figure 3 "Escalator" diagrams for the net force question

Transfer from mechanics to electrostatic contexts

Although around one third to almost half of the students answered both mechanics and electrostatics questions correctly, as shown in the upper left corner blocks (in dark grey) in the transfer diagrams on Figure 4, giving evidence of transfer, more than 40 % of students

in the algebra group (AC) and in the calculus group with traditional instruction (CT) are in the two light grey blocks (adding the numbers in them), showing evidence of lack of connection between the two contexts.

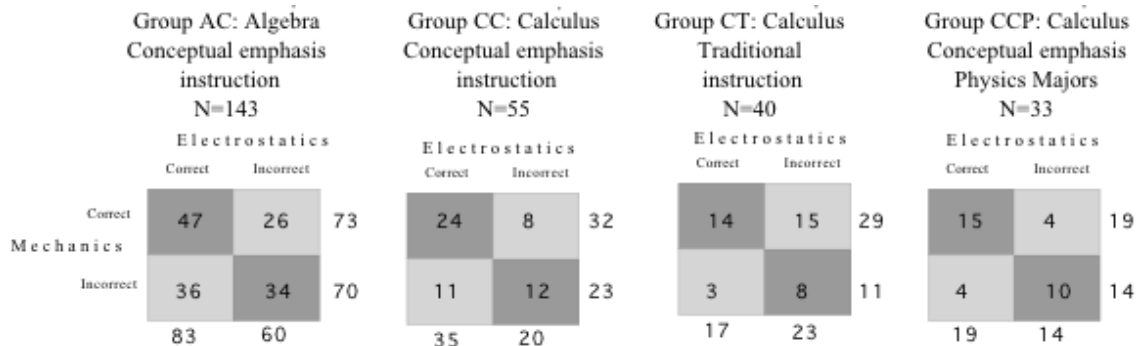
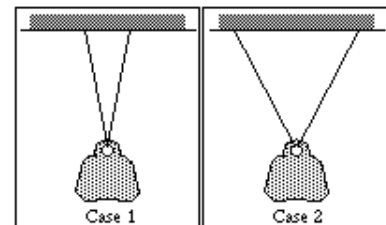


Figure 4 Transfer diagrams for the net force question

The most common incorrect answer was that the net force is greater in the case where only one force or one charge acts on the object in the mechanics context or on the $+Q_0$ charge in the electrostatics context. Around one third of the students in the four groups gave these incorrect answers. The percentage of students answering correctly and then incorrectly or vice versa using these answers goes from 10% to 20%, and from 10% to 20% used these incorrect answers in the two contexts.

Tension

A pair of questions involving tension in strings was included in the MEAT (Figure 5). We expect students to use superposition of vectors to find the correct answer. Difficulties with problems involving comparison of tension on strings at different angles have been identified and documented. Flores (2006) found that most students recognize that the magnitude of tension on strings depend on angle in static situations. The most common incorrect belief that Flores [1] found was that the tension in the string decreases when the angle that the string made with the vertical increases.



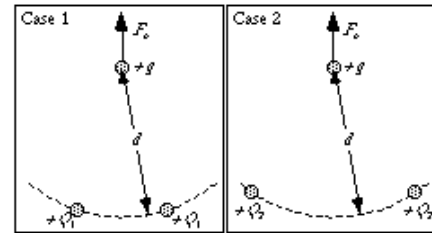
A 5-kilogram mass is suspended from two strings of equal length. Which of the following statements is true?

- (a) The tension in each string in case 1 is *greater than* the tension in each string in case 2.
- (b) The tension in each string in case 1 is *equal to* the tension in each string in case 2.

(c) The tension in each string in case 1 is *less than* the tension in each string in case 2.

(d) *There is not enough information* to compare the tension in the strings in the two cases.

In each case shown, the two lower charges exert a net force F_o on the charge $+q$. The force F_o and the charge $+q$ are the same in the two cases. The other charges in each case are the same distance d from $+q$, but in case 2 they are further from each other than in case 1. We can conclude that



(a) The magnitude of Q_1 is *equal to* the magnitude of Q_2 .

(b) The magnitude of Q_1 is *greater than* the magnitude of Q_2 .

(c) The magnitude of Q_1 is *less than* the magnitude of Q_2 .

(d) *There is not enough information* to compare the magnitudes of Q_1 and Q_2 .

Figure 5 Pair of questions about tension

Gain in the mechanics context

Students' performance in the mechanics context was poor, as shown in the escalator diagrams on Figure 6. Around 70% of students in three groups (AC, CC, and CT) answered incorrectly on the pretest. These percentages diminished about 10% after instruction. From 40% to 50% of students in these three groups answered incorrectly in both the pretest and the post-test. The physics major group (CCP) was the exception, in which the percentage of students answering correctly in the pre-test and incorrectly in the post-test was about 50%.

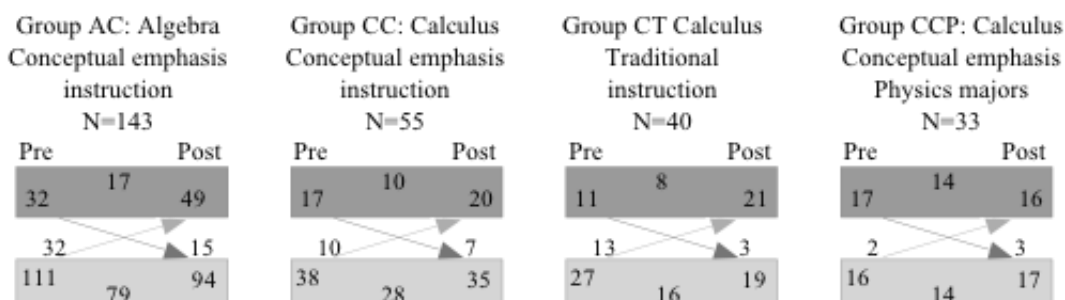


Figure 6 "Escalator" diagrams for tension

Transfer from mechanics to electrostatic contexts

Transfer diagrams for this pair of questions are shown in Figure 7. The physics major group (CCP) showed evidence of positive transfer, in contrast with groups CC and CT, which showed evidence of lack of transfer. The majority of students in the algebra group (AC) answered incorrectly in both contexts. It seems that the physics major group was better prepared in mechanics and consequently, better prepared to transfer from mechanics to statics.

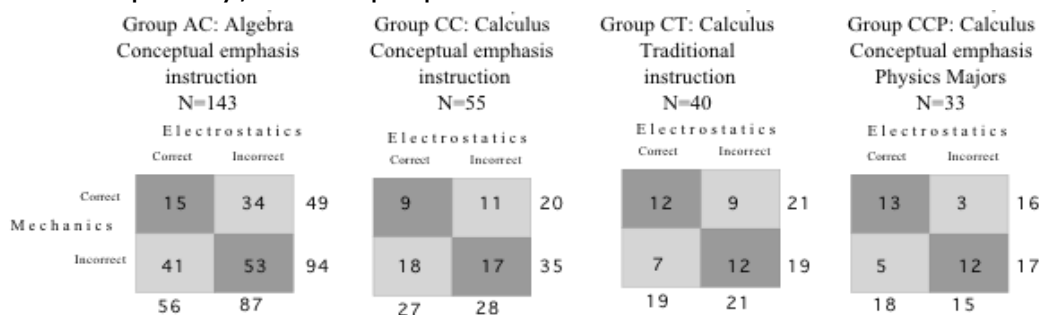


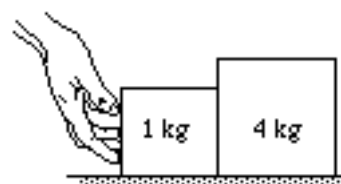
Figure 7 Transfer diagrams for tension electrostatics.

The most common incorrect answer to the mechanics and electrostatics questions was that the tension in each string and the magnitude of the charge is less in the case where the strings and the charges are closer to each other. This belief is in agreement with Flores's (2006) findings in his investigation. Half of the students in the algebra group (AC), and almost 40% of students in the group Calculus conceptual group (CC) gave this answer for the mechanics question. Around 30% of students in the four groups gave this answer for the electrostatics question. A second common incorrect answer was that the tension in each string and the magnitude of the charge is the same for both cases. 40% of students in the traditional group (CT) gave this answer for the mechanics question, and more than 30% for the electrostatics question.

Targeted transfer in Newtonian mechanics

Newton's 3rd law

There is a pair of questions on the MEAT about Newton's 3rd law (Figure 8). We expect students to apply Newton's 3rd law in both context to conclude that the forces exerted are equal.



A 1-kg block and a 4-kg block are pushed across a table as shown. The blocks are speeding up. Which of the following statements is true about the force exerted on the 4-kg block by the 1-kg block as compared to the force exerted on the 1-kg block by the 4-kg block?

- (a) It is *greater*.
- (b) It is *less*.
- (c) The two forces are *equal*.
- (d) *We do not have enough information* to compare these two forces.

A charged insulating rod with overall charge $+4q$ is placed near a small sphere of charge $+q$. Which of the following statements is true?

- (a) The electric force that the rod exerts on the sphere is *greater than* the electric force that the sphere exerts on the rod.
- (b) The electric force that the rod exerts on the sphere is *less than* the electric force that the sphere exerts on the rod.
- (c) The electric force that the rod exerts on the sphere is *equal to* the electric force that the sphere exerts on the rod.
- (d) *There is not enough information* to compare the two forces.

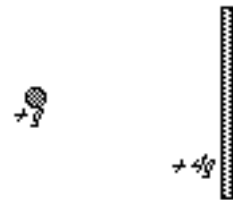


Figure 8 Paired questions about Newton's 3rd

Gain in the mechanics context

Figure 9 shows the students' performance for the mechanics question on the pretest and on the post-test for the four populations described previously. The number of students answering correctly in the mechanics context in groups receiving conceptual instruction (AC and CC) increased from the pretest to the post-test. The percentage of correct answers slightly increased from 73% to 85% for the algebra group (AC) and from 75% to 82% for the calculus group (CC). The normalized gain is 0.46 and 0.29 respectively. The number of correct answers for the other groups (CT and CCP) decreased slightly from the pretest to the post-test, from 65% to 58% and from 85% to 73% respectively. The normalized gain for these groups is negative: -0.21 and -0.8 respectively.

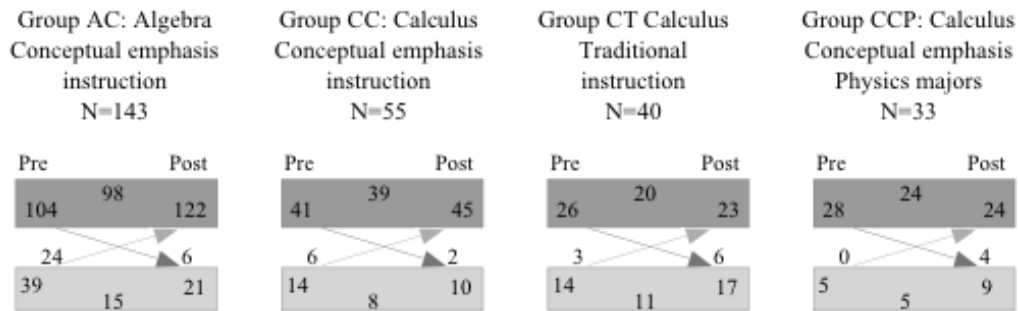


Figure 9 "Escalator" diagrams for Newton's 3rd law

Transfer from mechanics to electrostatic contexts

Figure 10 shows the transfer diagrams from mechanics to electrostatics of the four students' populations described above. For this question, the majority of students (between 48% and 67%) answered correctly in both contexts. General expectations are that students' performance would be better in the mechanics context than in the electrostatics context. These expectations were fulfilled for the algebra group (AC). The number of students answering correctly to mechanics context was about the same as the number of students answering correctly to the electrostatics context for the calculus groups CC and CCP. The traditional group CT presented an unexpected behavior, given that students' performance was better in the electrostatics context.

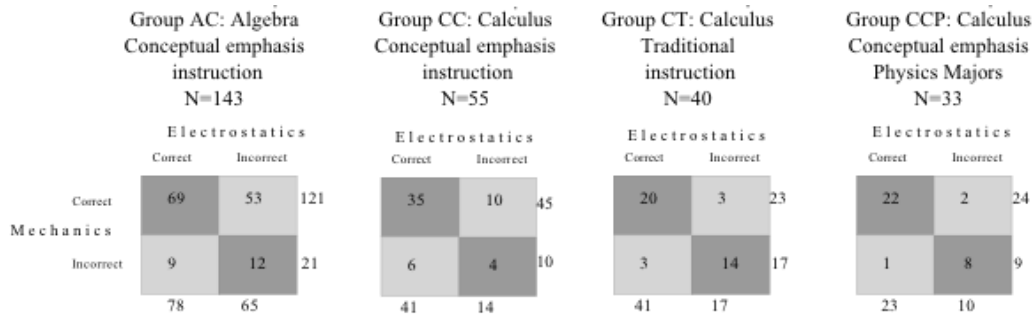


Figure 10 Transfer diagrams for Newton's 3rd law.

Overall, the performance of the four groups is good, given that we observed evidence of transfer in all of them. Newton's 3rd law seems to be well understood in the two contexts. Nevertheless, students seem to forget the concepts in the mechanics context, given that they are taking an introductory electricity and magnetism class. Groups AC and CC showed a desirable response to the instruction in the mechanics context, obtaining positive gains. Groups CT and CCP did not do as well, obtaining negative gains. A big negative gain was calculated for group CCP (-0.8). We noticed

that the difference between the percentage of incorrect and correct answer is not so big, therefore, the cause for this big negative value could be the small number of students in this group.

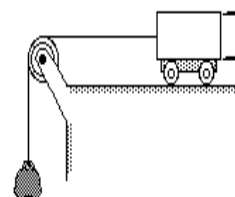
Newton's 2nd law

We included a pair of questions on the MEAT related to Newton 2nd law shown in Figure 11. On both questions, a constant force acts on the object, and both objects will accelerate until the force is no longer acting on them. The analogy between these two questions is clear to physicists but not to students. Students need to interpret how a proton would move in an electric field.

Gain in the mechanics context

We observed modest gain from pretest to post-test in the mechanical context in all three groups receiving instruction with strong conceptual emphasis, but negative gain in the group with traditional instruction. Positive gains were 0.63 for AC group, 0.09 for CCP group, and 0.31 for CC group. Negative gain of -0.06 was calculated for group CT (Figure 12).

A cart with wheels is placed on a horizontal table. A string tied to the cart passes over a pulley and is attached to a hanging weight as shown at right. The string pulls on the cart with a constant force, and friction can be ignored. If the cart is released from rest, which choice below best describes its motion?



- (a) The cart moves with a constant speed.
- (b) The cart quickly speeds up until it reaches a maximum speed that depends on the size of the weight.
- (c) The cart remains at rest unless the hanging weight is greater than the weight of the cart.
- (d) The cart is always speeding up until it hits the pulley.

A proton is projected into a uniform electric field. Which choice best describes the motion of the proton after it enters the field?

- (a) It moves with a constant speed.
- (b) It speeds up as long as it is in the field.
- (c) It speeds up until it reaches a maximum speed that depends on the strength of the field.
- (d) It slows down.

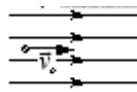


Figure 11 Paired questions about Newton's 2nd law

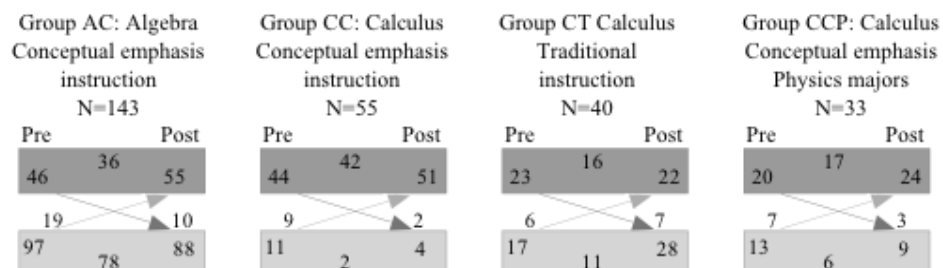


Figure 12 "Escalator" diagrams for Newton's 2nd law

Transfer from mechanics to electrostatic contexts

Nevertheless, looking at the transfer diagrams for Newton's 2nd law (Figure 13), only the group with physics major's students on it (Group CCP) showed evidence of positive transfer (the largest number on the transfer diagram is on the upper left corner). The other three groups' answers (AC, CC, and CT groups) were mostly incorrect in the two contexts (the largest numbers on each diagram is on the lower right corner). The most common incorrect answer was that the cart remains at rest unless the hanging weight is greater than the weight of the car in the mechanics context and that the proton moves with a constant speed in the electrostatics context. The number of students using the same argument to answer incorrectly to this pair of questions is not significant. The majority of students in the four groups answered correctly to the mechanics context, as expected. For example, the transfer diagram for group AC shows 55 students answering correctly to the mechanics question and 35 to the electrostatics question.

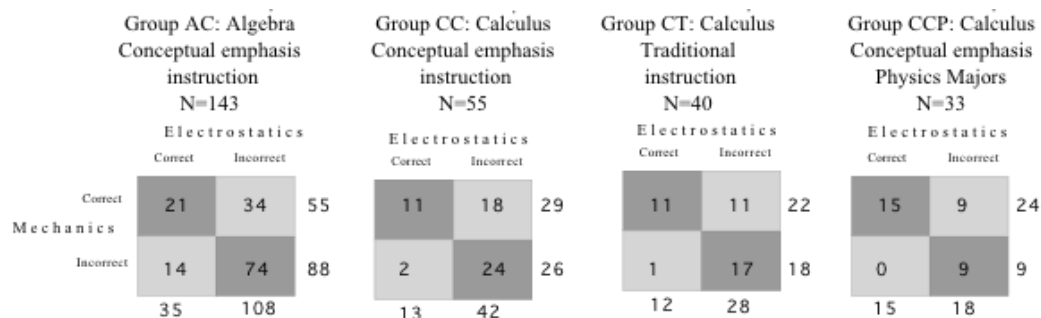


Figure 13 Transfer diagrams for Newton's 2nd law paired questions

It seems that unless the Newton 2nd law equation, $F = ma$, is widely known, the concepts related with it, like acceleration, are not fully understood and the students did not see the analogy with electrostatics that we expected. The additional difficulties we mentioned previously could be among the reasons for why students are not showing evidence of transfer for this pair of questions.

Energy conservation

Potential and kinetic energy

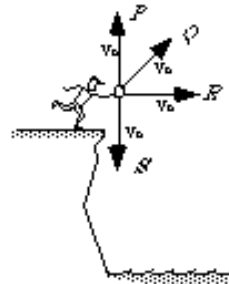
We designed a pair of questions intended to measure whether students apply ideas about energy conservation. The speed of the four thrown rocks and the four launched charges in the moment they hit the water or the plates of the capacitor is the same because the initial potential energy is equal to the final kinetic energy $U_i = K_f$

or $mgh = \frac{1}{2}mv^2$; solving for v : $v = \sqrt{2gh}$. This expression does not depend on any other quantity different from g or h ; which are the same for all the four rocks and the positive charges. Figure 14 shows the pair of questions about energy conservation, and Figure 15 shows students' performance on the pretest and post-test in the mechanics context.

Four rocks, all with the same mass, are thrown off a cliff. The rocks are thrown with the same speed but in different directions as shown.

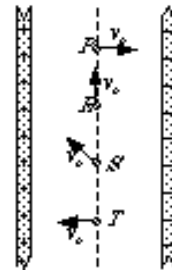
Which of the rocks will hit the water with the greatest speed? (*Hint: Consider energy!*)

- (a) P
- (b) P and S
- (c) S
- (d) R and S



- (e) All hit with the same speed.

Four identical positive charges are each launched with a speed v_0 from a line halfway between the plates of a parallel-plate capacitor. (Only a small portion near the center of the capacitor is shown in the diagram at right.) They are launched in different directions as shown. None of the particles touch the positive plate of the capacitor.



Which of the particles will hit the negative plate with the greatest speed? *Hint: Consider energy!*

- (a) T
- (b) T and P
- (c) P
- (d) R and P
- (e) All hit with the same speed

Figura 14 Pair of questions about energy conservation

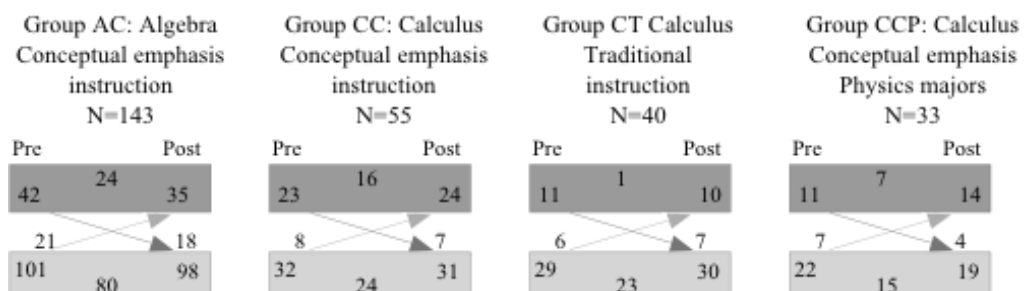


Figura 15 "Escalator" diagrams for the energy conservation question

Overall, students performed poorly on this question. However, we measured small positive gains for the three groups receiving instruction with strong conceptual emphasis. The results suggest that students are not acquiring a conceptual understanding of

conservation of energy in the mechanics context and consequently, we should not expect them to transfer knowledge to the electrostatics context. We can see in the transfer diagrams (Figure 16) that the majority of students in the four groups answered incorrectly in both contexts.

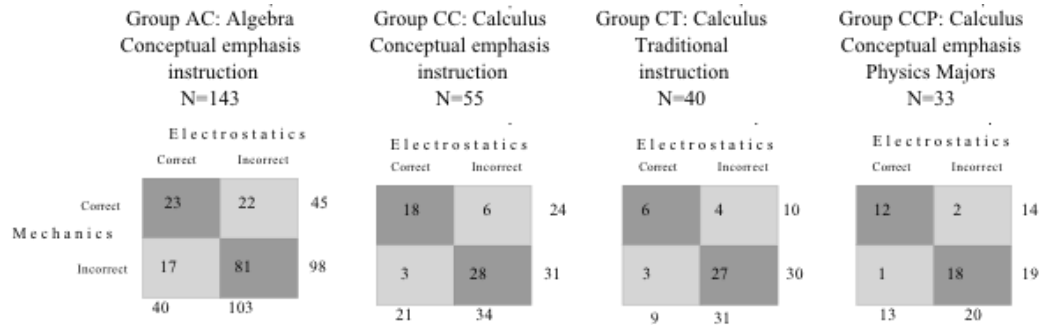


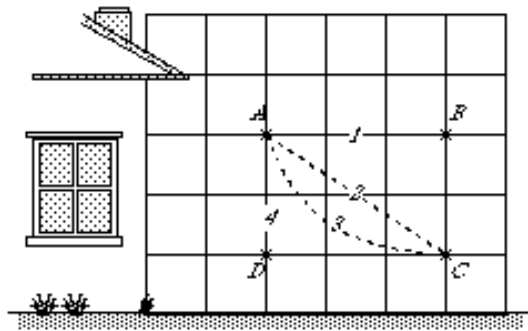
Figure 16 Transfer diagrams for the energy conservation pair of questions

The most common incorrect answer for the four groups was that the rock P , thrown up would hit the water with the greatest speed in the mechanics context. In the electrostatics context, the most common incorrect answer was that the particle T , going towards the negative plate would hit the negative plate with the greatest speed. These two answers correspond to the same incorrect concept in the two contexts. It seems that the majority of students' belief is that the rock and the particle would acquire more speed because they would spend more time in the air or in the electric field.

Path independence in a conservative field

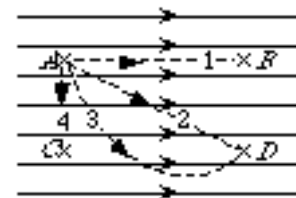
A third pair of questions was included in the MEAT to probe students' understanding of conservation of energy (Figure 17). We intended to know whether students know that the work done on objects in conservative fields is independent of the trajectory. The work done on the mass by the earth to displace an object from point A to D and to C along trajectories 4, 3, and 2 is the same, and no work is done along trajectory 1. Analogously, the potential difference between the initial and final points following trajectories 1, 2, and 3 within an electric field is the same, and there is no potential difference between points A and B .

Four points that lie in a vertical plane are shown. A mass is moved from point *A* along different paths to points *B*, *C*, and *D*. The mass starts at rest at point *A* and ends at rest at the other points. Rank (from largest to smallest) the work done on the mass by the earth along the paths 1 – 4.



- (a) The work done is the same along all paths.
- (b) Path 3 > Path 2 > Path 1 > Path 4
- (c) Path 4 = Path 2 = Path 3 > Path 1
- (d) Path 3 = Path 2 > Path 1 > Path 4
- (e) Path 3 = Path 2 = Path 1 > Path 4

Four points that lie in a region containing a uniform electric field are shown at right. Rank (from largest to smallest) the magnitudes of the electric potential differences along the paths shown from point *A* to points *B*, *C*, and *D*.



- (a) The electric potential difference is the same along all paths.
- (b) Path 3 > Path 2 > Path 1 > Path 4
- (c) Path 3 = Path 2 > Path 1 > Path 4
- (d) Path 4 = Path 2 = Path 3 > Path 1
- (e) Path 3 = Path 2 = Path 1 > Path 4

Figure 17 Pair of questions for path independence

Students' performance in the mechanics context was poor (Figure 18). The number of students answering incorrectly in both, the pretest and the post-test in the AC, CC, and CT groups is large. The number of students in the physics major group (CCP) answering correctly or incorrectly is about the same. The gain in the mechanics context was small positive for groups AC, CC, and CCP (0.11, 0.25, and 0.17), but small negative for group CT (-.03).

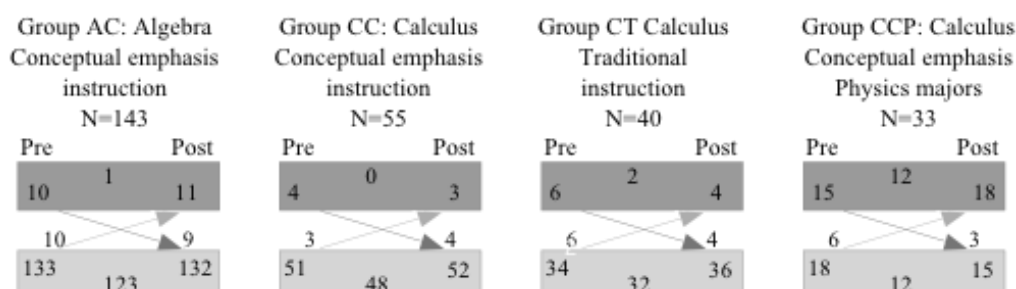


Figure 18 "Escalator" diagrams for the path independence question

Transfer from mechanics to electrostatic contexts

According to the poor performance in the mechanics question, the majority of students in the four groups answered incorrectly in both the mechanics and the electrostatics context, as shown in Figure 19. The number of students answering correctly in the CCP group is about the same than the number of students answering incorrectly to both contexts. The number of correct answers in the mechanics context for the CT group was less than the number of correct answers in the electrostatics context (9 and 16), contrary to our expectations.

The most common incorrect answer for the algebra group (AC) was the second option: path 3 > path 2 > path 1 > path 4 in both the mechanics and the electrostatics questions. The error that students made was to rank from largest to smallest the length of the trajectory. 48 students in the mechanics question and 42 students in the electrostatics question chose this option, 26 of them in the two contexts. The option 4 in the electrostatics question: path 4 = path 2 = path 3 > path 1 was the most common incorrect answer for groups CC and CCP (28 and 10 students respectively). This option is equal to the correct option in the mechanics question (option 3), but it is not the correct option to the electrostatics question because the direction of the electric field is to the right. 18 students in the CC group and 7 in the CCP group chose this combination (options 3 and 4). The option 4 in the mechanics question: path 3 = path 2 > path 1 > path 4 was most common incorrect answer for group CT (12 students). Apparently, students ranked from largest to smallest the distance between the points. The incorrect answers in the electrostatics question for group CT were evenly distributed among three options (1, 3, and 4), seven students chose each of these options.

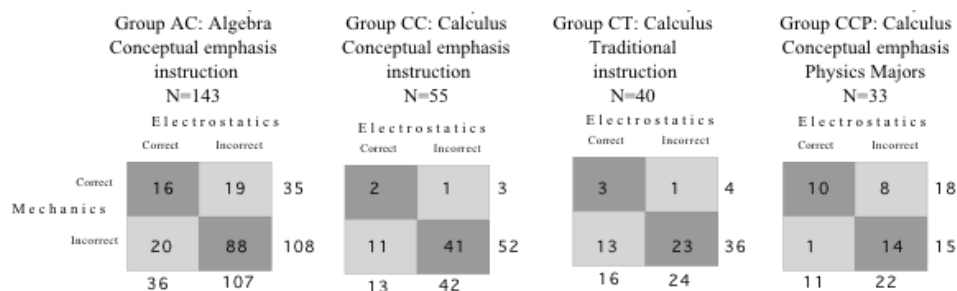


Figure 19 Transfer diagrams for the path independence question

It seems that path independence in conservative fields is a difficult topic for the majority of students in this study. The results suggest that students begin the semester without a previous understanding of path independence, and that students did not acquire the required understanding after instruction. The results in the transfer analysis were expected after their performance in the mechanics context. Students cannot transfer a nonexistent knowledge. 26 students in the group AC, which chose option 2 for both questions, could be transferring the belief that work and potential difference depends on the length of the trajectory. Other 4 students in the group CT, which chose options 4 and 3 in the mechanics and electrostatics questions, could be transferring the incorrect belief that work and potential difference depends on the distance between the points in the gravitational and electrical field respectively.

Conclusions

Success in Electricity and Magnetism course depends less on 'overcoming' misconceptions and more strongly on what students learned in mechanics and on their ability to map the ideas introduced in the first semester course onto the new and unfamiliar context of E&M. The misconceptions that are so prevalent in mechanics occur because these rules are not the same as the rules of physics. In contrast, students have very little concrete experience with electric and magnetic phenomena, and so the incorrect ideas about these topics are less likely to be strongly held.

The results varied through the different populations we investigated and through the physics concepts we probed. In general, groups receiving calculus-based instruction showed a better performance than groups receiving an algebra-based instruction.

Similarly, groups receiving instruction with conceptual emphasis performed better than groups receiving traditional instruction.

We observed the tendency to transfer knowledge from mechanics to E&M in questions about Newtonian mechanics and the representation of acceleration and electric field in graphs. We observed lack of transfer in the question about net force. The majority of the students' responses were incorrect in questions related with conservation of energy, as potential and kinetic energy, and path independence.

The use of misconceptions that physics education researchers had found previously prevailed in questions about force concepts: net force and tension. Two examples are the tendency to add vectors as scalars, and the belief that the tension on strings and magnitudes of the charges is less when the strings or charges are closer to each other.

Future work consist in the use of different approaches to measure transfer, as Preparation for Future Learning [9]. Our expectations as educators is to obtain a better measure of transfer to be able to design activities that better help students to transfer knowledge as it has been considered as the ultimate goal in education [10].

Bibliographic References

- Atkins, L.J. (2004). *Analogies as categorization phenomena: studies from scientific discourse*. (Ph.D. Dissertation). Maryland: University of Maryland.
- Bransford, J. D., Brown, A. L., & Cocking, R. R. (1999). *How people learn: Brain, mind, experience, and school*. National Academy Press.
- Detterman, D. K. (1993). The case for the prosecution: Transfer as an epiphenomenon. *Transfer on trial: Intelligence, cognition, and instruction*. (pp. 99-167). Norwood, NJ: Ablex.
- Flores S. (2006). *Student use of vectors in mechanics*. (Ph. D. Dissertation). Las Cruces, New Mexico: State University.
- Flores S., Gonzalez M.D. & Carrillo V. (2014). *Transfer of learning from mechanics to electricity and magnetism*. Scholar's Press.
- Flores S., Kanim S & Kautz. (2004). Students use of vectors in introductory mechanics *American Journal of physics*, 72 (4), 460-468.

- Gonzalez, M.D. (2013). *Transfer and measures of transfer*. (Ph. D. Dissertation). Las Cruces, New Mexico :State University.
- Kanim S. (1999). *An investigation of student difficulties in qualitative and quantitative problem solving: Examples from electric circuits and electrostatics*. (Ph. D. Dissertation). Seattle, WA: University of Washington.
- Mckeough, R. E., Lupart, J., & Marini, A. (Eds). (1995). *Teaching for transfer: Fostering generalization in learning*, Mahawah: Autores.
- Schwartz, D. L., Bransford, J. D., & Sears, D. (2005). *Efficiency and innovation in transfer. Transfer of learning from a modern multidisciplinary perspective*. (pp.1-51). Age Publishing.