THE EFFECT OF DISTRACTERS ON STUDENT PERFORMANCE ON THE FORCE CONCEPT INVENTORY*

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ABSTRACT

We compared students' responses on four multiple-choice FCI questions with similar responses on equivalent open-ended questions. In Phase-I of the study students in an introductory algebra-based course responded to two questionnaires each containing two open-ended and two multiple-choice questions. The open-ended responses were categorized and used as multiple-choices in Phase-II of the study.

Our results indicate a good agreement between the percentages of correct responses in each of the two formats, indicating that distracters on the FCI do not adversely affect performance as measured by the number of correct answers. However, a significant percentage of the incorrect open-ended responses fall into categories that are not included in the FCI multiple choices. When these alternative categories were presented to the students as distracters in a revised multiple-choice format, a significant percentage of the students chose these alternative responses.

INTRODUCTION

Teachers and researchers have often speculated that the presence of distracters in multiple-choice Force Concept Inventory (FCI) [1,2] questions could bias students toward the incorrect answer and inaccurately measure students' conceptual understanding. Steinberg and Sabella[3] have shown that students performed better on open-ended exam questions than on FCI questions based on the same concept. However, in their study most of the exam questions were not identical to any of the FCI questions, instead the open-ended exam question evaluated student knowledge on the same concept as a corresponding FCI question.

Recently, Schecker and Gerdes[4] analyzed the Force Concept Inventory as a tool for understanding the model that students applied in dynamics problems. They assumed that students would generally hold one of three models -- Aristotelian, Impetus or Newtonian. To determine the students' model they needed to look beyond the right answers and see which wrong answers the students selected. Then, they needed to determine if the students consistently selected the wrong answer associated with the same model. However, the FCI did not lend itself well to such an analysis because all three models were not represented in each of the questions about forces. Thus, an analysis of wrong answers could not determine the students' preferred models.

Schecker and Gerdes also investigated briefly how the context of the question may affect the students' responses. One of the questions on the FCI asks students to select an answer to describe the forces on a golf ball after it has been hit and is traveling in the air toward a green. They modified the question slightly and asked the students to describe the forces on a soccer ball after it has been kicked and is traveling through the air toward a goal. For the golf ball problem 42 of 87 students included a force in the direction of motion. However, when faced with an

identical problem involving a soccer ball 23 of these 42 students selected either only gravity or gravity plus air resistance. A similar behavior was noted on another question. The authors concluded that the students' model is dependent on the context.

The lack of consistency was also evident in the models that students applied to problems that involved the same physics but were not simple variations of each other. The choice of model depended on the context and the situation presented. This lack of consistency led the authors to conclude that these students were in a mixed state (Mischzustand). Sometimes the students applied one model; sometimes, another. Other research[5] has shown that naïve student beliefs may be too fragmented to characterize any kind of mental model. For instance, DiSessa[7] prefers to describe student knowledge as a cluster of phenomenological primitives or "p-prims". p-prims can be either right or wrong depending upon the context in which they are triggered.

The study of the mental models that students apply in various FCI questions is beyond the scope of this study. Rather this study aims to learn more about the effectiveness of the distracters that are currently used on the FCI, and whether alternative distracters would be more effective than the ones currently used.

The results of both studies indicate that the incorrect answers (distracters) may need further investigation. We were motivated to look at these distracters in detail for two additional reasons:

1. Ten years have passed since the FCI was constructed. Changes in instructional procedures and student experiences, both in and out of the classroom, may have changed the value of the present distracters.
2. Hestenes[2] and coworkers designed the FCI from the Mechanics Diagnostic Test[8] that they had originally developed based on research by others.[10] The FCI questions were

validated through interviews of students over a large range of physics backgrounds from 9th grade to graduate level. The target audience of the FCI may or may not have the same physics background as the population that was interviewed to create the FCI. Thus, it is worthwhile to investigate whether the distracters are effective for students with a particular background.

To investigate this situation further we completed a two-phase investigation. In Phase-I we compared student performance on four FCI questions with performance on the same questions that have been rephrased as open-ended questions. Then in Phase-II, we used the responses to these open-ended questions, and created multiple-choice questions with new sets of distracters.

The FCI has been very successful in meeting the objectives for which it was designed.

First, the FCI is designed to test for a minimal understanding of Newtonian concepts. This is accomplished by asking students to select the Newtonian concept over other common sense alternatives that might be more appealing. The FCI is very successful at meeting this objective because it has a very small percentage of false negatives (selection of a non-Newtonian choice by students who in fact understand Newtonian mechanics) or false positives (selection of a Newtonian choice by students who in fact do not understand Newtonian mechanics).

Second, the FCI is designed to call to the teacher's attention student misconceptions. The authors of the FCI have cautioned that it is indeed in this area that the FCI is most prone to misinterpretation, because it is important not to read too much into the responses of a single or even a small subset of the FCI questions. The author's data[2] suggest a Newtonian "threshold" of about 60% correct on the entire FCI as a reasonable benchmark. Since this research focuses on

an in-depth analysis of distracters on only four FCI questions, the results that we present do not detract from the overall usefulness of the FCI.

In this study we do not investigate how the FCI has met its goals. Instead, we use questions from the FCI to examine a broader issue – how students respond to multiple choice and open-ended questions on the same topic and what we can learn from the differences in these responses.

PHASE I

Instruments

We developed a set of instruments based on four questions from the most recent version of the FCI. We chose questions that, based on published data[2], addressed the largest number of misconceptions.

For each of these questions we created an equivalent open-ended question. With one exception, the open-ended question required only trivial changes and removal of the five choices. FCI Question # 15 has multiple-choices that needed more extensive rewriting as an open-ended question. With these eight questions -- four multiple-choice and four equivalent open-ended -- we created two questionnaires, each containing two questions of each type. Table 1 shows the contents of each questionnaire.

Each student received a questionnaire with two multiple choice and two open-ended questions. Half of the students in each class were randomly selected to respond to each version. In effect, students answering one questionnaire were the control group for those answering the other.

Procedure

After a pilot test we administered the questionnaires to 238 students in an algebra-based, introductory physics course. The questionnaire was presented on the first day of class as a diagnostic with no implications for student grades.

Using phenomenographic methods[1617] we categorized the open-ended responses. In this approach the researchers do not establish categories of responses in advance of reading the responses. Instead the categories are developed from the student responses. The categories are established, modified, and agreed upon by multiple readers. Then, each reader independently places all responses in one or more of the agreed upon categories. Using this procedure three researchers placed each response in a category. The reliability among the three researchers of this method for categorizing responses was more than 90%.

Results and Analysis of Phase-I

During this phase we were primarily interested in the comparison of open-ended responses with the concepts represented by the multiple-choice responses. In the discussion here we will consider each question individually and then draw some general conclusions.

Question-I

Responses to the multiple-choice and open-ended formats are shown in Figures 1(a) and 1(b) respectively. Categories 1, 2 and 3 of the open –ended responses all appear to be tangential to the circle, and have been combined. Categories 5 and 6 do not have equivalent multiple-choice responses. None of the categories for the open-ended responses are equivalent to Choices 1 or 3.

The percentages of correct responses in the open-ended and multiple-choice formats agree within 5%. However, the most frequent incorrect open-ended response is Category 4 (22%) that differs from the most frequent incorrect multiple-choice response (Choice 5, 11%). Also about 9% (Categories 5 and 6) of the responses in the open-ended format do not correspond to any multiple choices, and 22% (Choices 1 and 3) of the multiple-choice responses do not correspond to any of the categories in the open-ended questions.

Question-III

Responses to the multiple-choice and open-ended formats are shown in Figures 2(a) and 2(b) respectively. Category 3 (28%) in the open-ended responses is not one of the available multiple choices. None of the students selected choice 5 in the multiple-choice format.

Similar to Question-I, the percentages of correct responses in the open-ended and multiple-choice formats agree within 7%. Also, the most frequent incorrect response was Choice 2 (37%) in the multiple-choice format but Category 5 (28%) in the open-ended format, which had no equivalent multiple-choice response.

Question-IV

Responses to the multiple-choice and open-ended formats are shown in Table 2. Only two categories are similar to the FCI choices. We categorized responses that said the box would "stop" (Category 4), separately from those that said it would "stop suddenly/immediately" (Category 5) because in the latter case we are more certain of the student misconceptions than in the former. Category 2 was created for responses that the box would "stop if the floor was frictional, and continue if it was frictionless". These students were unable to identify the frictional interaction between the floor and box from the information in the problem.

Similar to Questions-I and III the percentages of correct responses in the open-ended and multiple-choice formats agree within 7%. The most frequent incorrect response was Choice 1 ("stops immediately" – 51%) in the multiple-choice format, and Category 4 ("stops" 43%) in the open-ended format. Only 5% of the open-ended responses mentioned that the motion of the box would depend upon friction (Category 2).

Question-II

This question was rewritten in the open-ended format with more significant changes than the other questions, and hence the data were analyzed differently. We divided the Question into three sub-questions each of which were categorized separately. Responses to the multiple-choice and open-ended formats are shown in Table 3.

Sub-question: "Does the Car Exert a Force on the Truck? ..."

Almost all (98%) of the students answered "yes" to this question. Hence, it appears that this question had an obvious answer, and need not have been asked.

Sub-question: "Does the Truck Exert a Force on the Car? ..."

Again, almost all (98%) of the students answered "yes" to this question. A second part of this sub-question asked the students to compare the forces of the car and the truck. This key sub-question addressed the primary misconception of the original FCI question. 42% of the open-ended responses and 61% of the multiple-choice responses were the correct answer. 49% of the open-ended response indicated that "the truck would exert more force than the car", while 60% of the students selected the corresponding Choice 3 in the multiple-choice format. Thus the distracter (Choice 3) in the multiple-choice format did have a significant impact on student performance.

Sub-question: "Will your answers to the above questions change if the engine of the truck were running? ..."

This sub-question was included to account for Choice 4 on the original FCI question. 61% of the students responded "No" to this question, and the remaining, "Yes". The most common reason given by those who responded "Yes" was that the "the truck was moving under its own power" or "the truck would exert less force". About 13% of the responses stated that

their answer would depend upon “the gear of the truck / car”. Among the students who responded “No,” about a third mentioned Newton's Third Law or related reasons. Sixteen percent said that there would be no difference as long as the truck/car were not accelerating.

In general, a significant number of students (over 35%) who had correctly answered the first two sub-questions, failed to answer the third-sub-question correctly. However, when we compare these results with the multiple-choice format we find that only 9% of the students selected Choice 4, which is the only choice that mentions the running engine. Thus, in this question, the FCI distracter (Choice 4) was not effective in misleading the students when they were asked to select from the five available FCI choices. However, when students were explicitly asked whether the running engine of the truck would make a difference to their answer, they responded “Yes”. Hence, we can conclude that, sub-question 3 on the open-ended format was effective in uncovering a conceptual difficulty that is not detected when students see the same idea expressed in only one of five choices. .

Summary of Phase-I Results

We measured no notable difference between student performances in terms of the percentage of correct responses on the two formats. Hence, if one is interested in the number of students who answer these FCI questions correctly, the multiple choice and open-ended formats give equivalent results.

The most frequent incorrect responses for each question varied significantly between the open-ended and multiple-choice. For Question-I and Question-III, the category of the most frequent response had no equivalent choice on the multiple-choice format. Conversely, at least one choice on multiple-choice format for Questions-I and III did not have any corresponding open-ended category, and were selected by only a few (<15%) on the multiple-choice formats.

For our students, more effective distracters derived from the category of the most frequently incorrect open-ended response could replace these choices. Hence, if the FCI is being used to identify the student's misconceptions, it is less effective than the equivalent open-ended questions.

From our results for Question II, we find that students who gave the correct response on the first two sub-questions frequently displayed a misconception on the third sub-question. Thus, a misconception stated in one of the multiple choices is not selected by any of the students, but it does appear when students are asked about it specifically.

In general, the multiple choice format of the FCI seems to be useful in determining which students choose the right answer, but is of limited value in determining the alternative conceptions for students who do not respond correctly.

PHASE-II

Instrument and Procedure

To determine whether categories which were uncovered in Phase I could be effective distracters we constructed three questionnaires. All of the questionnaires used the original FCI questions and had multiple-choice responses. They differed in the content of the distracters.

- Questionnaire A contains the original FCI distracters.
- In questionnaire B original distracters that were chosen by very few students were replaced with distracters constructed from categories mentioned frequently open-ended responses from Phase-I.
- Questionnaire C contains all of the distracters from both questionnaires A and B.

We administered the questionnaires to 234 students in an algebra-based introductory physics course. Each student completed one version of the questionnaire and was randomly matched with the version. Again, the questionnaire was presented as a diagnostic on the first day of class, with no implications on student grades.

Results and Analysis of Phase-II

Question-I

Responses to Question-I are shown in Figure 3. Choices 1 and 3 in the FCI questionnaire (A) have been replaced with other alternatives in questionnaire (B). This change causes the percentage of correct responses to increase by about 20%, which is approximately the percentage of students who were distracted toward Choices 1 and 3 in the FCI questionnaire. Choices 1 and 3 in questionnaire B (which are Choices 6 and 7 in questionnaire C), when presented as alternatives on a multiple-choice instrument, are less than 5% of the overall response.

These data indicate that Choices 1 and 3 on the FCI questionnaire (A) serve as effective distracters and will significantly alter the percentage of correct responses if they are omitted, as in questionnaire (B). On the open-ended response no students drew the curved path represented by choice 1 on questionnaire A and C. Those students who drew paths in the general direction of somewhere between a tangent to the circle and the circle itself, always drew straight lines. However, when presented with this alternative a rather sizable fraction of the students choose it.

These results indicate that the percentage of correct responses do depend upon the distracters used in a multiple-choice format, although some of these distracters may not correspond to responses to an open-ended version of the same question.

Question-III

Responses to Question-III are shown in Figure 4. The percentage of correct responses (Choice 4) decreases by at least 10% when Choice 5 on the original FCI questionnaire (A) is replaced by a new choice, a backward diagonal path (Choice 5 in B, Choice 6 in C). Conversely, over a fifth of the respondents select the backward parabolic path (Choice 1) in the FCI questionnaire (A), while only 5% select this choice when the backward diagonal path is also provided as a choice. Almost no respondents select Choice 5 in questionnaires A and C.

These data indicate that Choice 5 of the FCI questionnaire (A) is not as effective a distracter as the backward diagonal path (Choice 5 in B, Choice 6 in C). It also appears that students, who may have selected the backward diagonal path, instead select the backward parabolic path (Choice 1) in the original FCI, where the backward diagonal path is not provided.

These results indicate that the backward diagonal path serves as an effective distracter and should be introduced as a possible choice on the FCI. Alternatively, Choice 5 on the FCI can removed since almost nobody selected it in any of the questionnaires. The present choices on the FCI seem to be steering students toward a correct response even though they may prefer an alternative.

Question-IV

Responses to Question-IV are shown in Table 4. Over 60% of the respondents on the FCI questionnaire (A) selected the correct answer (Choice 3). When the distracter mentioning friction (Choice 4 in A, Choice 6 in C) is introduced, however, the results change dramatically. Over 60% of the respondents select this distracter in questionnaire A and nearly half in questionnaire C. About 13% of the respondents of Questionnaire B and about 21% of the respondents in Questionnaire C selected the correct answer. The FCI distracter (Choice 2 in A and C) "continues moving at a constant speed for a while and then slows to a stop" is chosen by

fewer than 10% of the students in either of the questionnaires. Similarly, hardly any respondents selected the FCI distracter "increases its speed for a while and then starts slowing to a stop" (Choice 5 in B and C) or FCI distracter "continues at a constant speed" (Choice 4 in B and C).

Three of the distracters on the original FCI question are selected by virtually no students. Conversely the distracter that points students toward friction appears to be extremely effective and changes the percentage of correct response from 60% to less than 25%. This distracter is also selected by 60% of the respondents. This new distracter concerning friction uncovers a previously hidden misconception about friction.

Of course, one needs to discuss whether this choice is a correct answer. Given an answer that includes a lack of friction, students may choose it "to be safe." They may have become accustomed to textbook situations in which frictionless surfaces are present and thus choose an answer that covers both friction and non-friction. If we allow both the answer "Immediately starts slowing" and the one that explicitly mentions friction as correct, the number of correct responses for this question increase by 9% for version B and by 6% for version C. These correct answers seem to be from students who would choose "immediately comes to a stop" or "continues to move at a constant speed then comes to a stop." Thus, in this case we seem to be seeing a complex interaction in which the students' selections of answers are dependent not only on the answer they choose but on the others that are available.

Question-II

Responses to Question-II are shown in Table 5. In each of the three questionnaires, about 60% of the respondents stated that the force of the car is greater than that of the truck, and about 15% stated that the force of the truck is greater than that of the car. Also, in each of the three questionnaires about 20% of the respondents selected the correct response (equal forces).

Very few (< 10%) of the students selected the other FCI distracters (Choices 4 and 5 in questionnaire A).

The revised format consisted of two sub-questions to accommodate the categories of open-ended responses from Phase-I. In Sub-Question-II over one half of the respondents in questionnaires B and C indicated that their response would not change if the engine of the truck were running. About a third of the respondents indicated that their response would change depending upon the gear in which the truck is operating.

These data indicate that Choices 4 and 5 on the original FCI (questionnaire A) are not effective distracters because they are selected by less than 10% of the respondents. There is good agreement (within 10%) between the responses that compare the forces of the truck and the car, with most of the students incorrectly stating that the force of the car is greater than that of the truck. However nearly one third of the students incorrectly indicated that their response would change depending upon the gear of the truck.

These results indicate that the choice specifically asking them whether their response would change depending upon the gear of the truck serves as an effective analysis of their understanding. Choices 4 and 5 on the FCI can removed since fewer than 10% of the respondents selected them in any of the questionnaires. Here, the presence of a new distracter ("answer depends upon gear of truck") when asked as a specific question evokes incorrect responses, and may possibly uncover a previously hidden misconception regarding Newton's Third Law.

Summary of Phase-II Results

Based on the results for these four questions we notice that in most cases the incorrect responses to the open-ended questions in Phase-I can serve as effective distracters when introduced as choices in the multiple-choice format. Some of these distracters (Questions II and

IV) may uncover misconceptions that may not have been addressed in the existing FCI choices. These revised distracters could possibly replace some of the existing FCI distracters. In versions where both the FCI distracters as well as the revised distracters were presented, the latter tended to dominate.

Summary and Conclusions of the Study

We selected four FCI questions that addressed the most number of misconceptions. In Phase-I we presented these questions in two questionnaires each containing two open-ended and two multiple-choice questions. The open-ended responses were categorized and compared with the multiple-choice responses.

In Phase-II we created revised multiple-choice distracters based on the categories of the open-ended responses in Phase-I. We compared the student performance on three versions of each question: original FCI, with the revised distracters, with a combination of the revised distracters and the original FCI choices.

Based on our results for these four questions we conclude the following:

1. The percentage of correct responses to an open-ended version of the FCI question does not differ significantly with the percentage of correct responses to the multiple-choice (original) FCI question.
2. The categories of the open-ended responses do not exactly match the choices provided on the original FCI question. Often a significant percentage of incorrect open-ended responses will not have equivalent multiple-choice distracters.
3. The distracters on the original FCI question alter the distribution of the incorrect responses, although they may not significantly affect the percentage of correct responses.

4. When the categories of the open-ended responses are presented as alternative distracters in a multiple-choice format, they may significantly alter the percentage of correct responses. Often these categories that were taken from incorrect open-ended responses serve as more effective distracters than the original FCI distracters.

Impact

Based on these conclusions we believe that the FCI in its present form is as effective for determining the percentage of students who can provide the correct answer as an open-ended question. However, a significant percentage of open-ended responses are not any of the distracters on the present FCI questions. Thus, analysis of the incorrect responses to FCI questions may not be an effective way to determine which parts of their conceptual understanding are deficient. This conclusion is similar to one discussed by Schecker and Gerdes who looked at the FCI as a possible way to determine the students' underlying model for describing motion.

If a revised version of the FCI questions with distracters extracted from open-ended responses such as the ones that our students gave were created, the percentage of correct responses on this revised FCI could be quite different from the original FCI. It should serve as a better tool for determining students' alternative conceptions.

The FCI was originally created using responses supplied by students to open-ended questions. Why then do we find that several of the open-ended responses do not correspond to any of the FCI choices? Also, why do we find that when these open-ended responses are presented as alternative distracters they can significantly affect the percentage of correct responses? We note that the original FCI was created using open-ended response supplied by high-school students approximately ten years ago. However, the participants in our study were

just beginning their introductory undergraduate physics course. Some of them had completed a high school physics course and all of them were somewhat older than students in the original sample for constructing the FCI. Further, the focus on change in physics instruction, brought about in part by results on the FCI over the past ten years could have influenced what the students have learned and thus their conceptions of the laws of motion.

A broader impact of the study is the implication for all multiple-choice instruments. Many such instruments are used in pre- post-instruction analysis. The effect of distracters could change during the course of instruction. The distracters that are effective before students have completed instruction may be ineffective or more effective after instruction. Further students may develop a new set of alternative conceptions, which are not addressed in the instrument. This phenomenon could possibly lead to pre- post- comparisons that do not accurately reflect the level of student understanding or lack thereof that they have acquired.

Acknowledgements

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TABLE CAPTIONS

Table 1. The multiple-choice (FCI) and equivalent open-ended questions in each questionnaire. The number in the parentheses in the left-most column is the question number on the latest version of the FCI.

Table 2. Responses to multiple-choice and open-ended versions of Question-IV in Phase-I. The open-ended responses were categorized. The percentages of each response are shown.

Table 3. Responses to multiple-choice and open-ended versions of Question-II in Phase-I. The open-ended responses were categorized. The percentages of each response are shown.

Table 4. Responses to the 3 multiple-choice versions of Question-IV in Phase-II. The percentages of each response are shown.

Table 5. Responses to the 3 multiple-choice versions of Question-II in Phase-II. This question was subdivided into two sub-questions based on the open-ended categories in Phase-I. The percentages of each response are shown.

FIGURE CAPTIONS

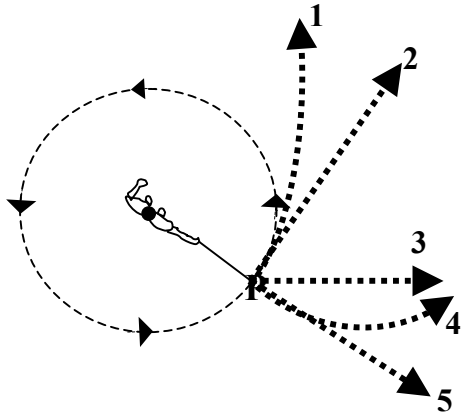
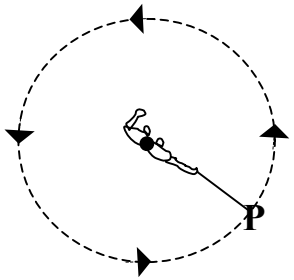
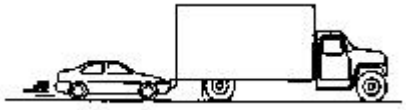
Figure 1. Responses to multiple-choice and open-ended versions of Question-I in Phase-I. The open-ended responses were categorized. The percentages of each response are shown.

Figure 2. Responses to multiple-choice and open-ended versions of Question-III in Phase-I. The open-ended responses were categorized. The percentages of each response are shown.

Figure 3. Responses to the three multiple-choice versions of Question-I in Phase-II. The percentages of each response are shown.

Figure 4. Responses to the three multiple-choice versions of Question-III in Phase-II. The percentages of each response are shown.

TABLE 1

Q#	Questionnaire A	Questionnaire B
I	A steel ball is attached to a string and swung in a circular path in a horizontal plane as illustrated in the figure below. At point P the string suddenly breaks near the ball. If these events are observed from directly above…	
(7)	which of the paths 1-5 below would the ball most closely follow after the string breaks. 	indicate on the diagram below the path which the ball would most closely follow if the string breaks. 
II	A large truck breaks down out on the road and receives a push back into town by a small compact car as shown in the figure below.  While the car still pushing the truck is speeding up to get up to cruising speed…	
(15)		

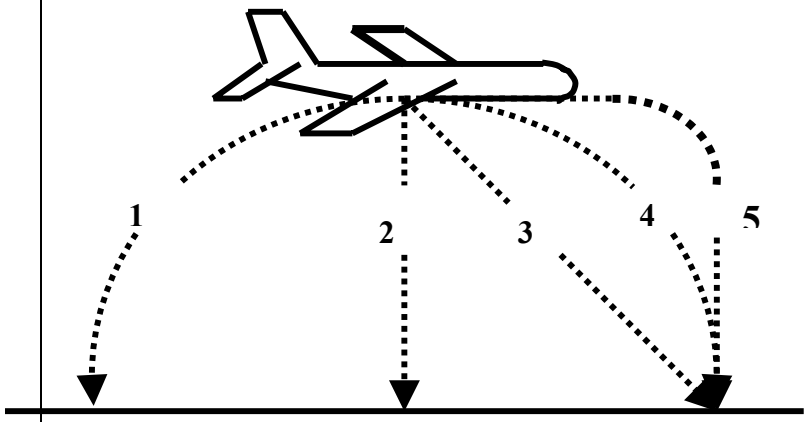
	• Does the car exert a force on the truck? • Does the truck exert a force on the car? If so, how does it compare with the force exerted by the car on the truck? • Will your answers to the above question change if the engine of the truck were running?	1. The amount of force with which the car pushes on the truck is equal to that which the truck pushes back on the car. 2. The amount of forced which the care pushes on the truck is smaller than that with which the truck pushes back on the car. 3. The amount of forced which the care pushes on the truck is smaller than that with which the truck pushes back on the car. 4. The car's engine is running so the car pushes against the truck, but the truck's engine is not running so the truck cannot push back against the car. The truck is pushed back simply because it is the way of the car. 5. Neither the car nor the truck exerts any force on the other. The truck is pushed forward simply because it is in the way of the car.

III

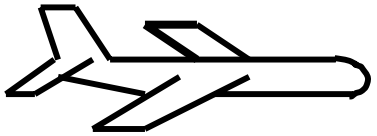
(14)

A bowling ball accidentally falls out of the cargo bay of an airliner as it flies along in a horizontal direction. As observed by a person standing on the ground and viewing the plane as in the figure below.

which of the paths 1-5 would the bowling ball most closely follow after leaving the plane?



Indicate on the diagram the path that the ball would most closely follow after leaving the plane?



IV

(27)

A woman exerts a constant horizontal force on a large box. As a result the box moves across the floor at a constant speed v_o. If the woman suddenly stops applying the horizontal force to the block…

Describe the motion of the block.

Circle the correct statement.

1. Immediately comes to a stop.
2. Continues moving at a constant speed for a while and then slows to a stop.
3. Immediately starts slowing to a stop.
4. Continues at a constant speed.
5. Increases its speed for a while and then starts slowing to a stop.

TABLE 2

Multiple-Choice	Open-Ended
1 (51%)	**1 (3%):** continues at a constant speed.
2 (3%)	**2 (9%):** with friction slowly stops, without friction continues at same speed.
3 (39%)	**3 (32%):** slows to a stop.
4 (2%)	**4 (43%):** stops.
5 (4%).	**5 (10%):** stops suddenly.

TABLE 3

Multiple-Choice	Open-Ended
1(22%) **2(9%)** **3(60%)** **4(9%)** **5(0%)**	**Does the Car exert a force on the Truck?** **98%** Yes **2%** No.
	Does the Truck exert a force on the Car? **98%** Yes **2%** No. **If so, how does it compare with the force exerted by the car on the truck?** **42%** Equal Forces **49%** Truck exerts less force than Car. **9%** Truck exerts more force than Car.
	Will your answers to the above question change if the engine of the truck were running? **39%** Yes **Reasons:** **50%** Truck exerts more force. **50%** Truck under own power. **39%** Yes **Reasons:** **37%** Truck under own power. **37%** Truck exerts less force. **14%** Depends upon gear of car. **5%** Friction against car is less. **2%** Truck is accelerating.

TABLE 4

FCI Choices (QUESTIONNAIRE A)	Alternative Distracters (QUESTIONNAIRE B)	FCI + Alternative (QUESTIONNAIRE C)
1 (25%): immediately comes to a stop.	**1 (21%):** immediately comes to a stop.	**1 (16%):** immediately comes to a stop.
2 (5%): continues moving at a constant speed for a while and then comes to a stop.	**2 (13%):** immediately starts slowing to a stop.	**2 (9%):** continues moving at a constant speed for a while and then comes to a stop.
3 (64%): immediately starts slowing to a stop.	**3 (1%):** continues at a constant speed.	**3 (21%):** immediately starts slowing to a stop.
4 (1%): continues at a constant speed.	**4 (60%):** continues at the same speed if the ground is non-frictional. If the ground is frictional it slows to a stop.	**4 (0%):** continues at a constant speed.
5 (0%): increases its speed for a while and then starts slowing to a stop.		**5 (0%):** increases its speed for a while and then starts slowing to a stop.
		6 (49%): continues at the same speed if the ground is non-frictional. If the ground is frictional it slows to a stop.

TABLE 5

FCI CHOICES (QUESTIONNAIRE A)	ALTERNATIVE DISTRACTERS (QUESTIONNAIRE B)	FCI +ALTERNATIVE (QUESTIONNAIRE C)
1(22%): The amount of force with which the car pushes on the truck is equal to the force with which the truck pushes back on the car. **2(9%):** The amount of force with which the car pushes on the truck is smaller than the force with which the truck pushes back on the car. **3(60%):** The amount of force with which the car pushes on the truck is greater than the force with which the truck pushes back on the car. **4(9%):** The car's engine is running so the car pushes against the truck, but the truck's engine is not running, so the truck cannot push back on the car. The truck is pushed forward simply because it is in the way of the car. **5(0%):** Neither the car nor the truck exerts any force on the other. The truck is pushed forward simply because it is in the way of the car.	**Sub-Question 1:** **How does the force exerted on the truck compare with the force exerted on the car?** **1(23%)**: Force with which the car pushes on the truck is equal to that which the truck pushes back on the car. **2(14%)**: Force with which the car pushes on the truck is smaller than that which the truck pushes back on the car. **3(63%)**: Force with which the car pushes on the truck is greater than which the truck pushes back on the car.	**Sub-Question 1:** **How does the force exerted on the truck compare with the force exerted on the car?** **1(21%)**: Force with which the car pushes on the truck is equal to that which the truck pushes back on the car. **2(12%)**: Force with which the car pushes on the truck is smaller than that which the truck pushes back on the car. **3(60%)**: Force with which the car pushes on the truck is greater than which the truck pushes back on the car. **4(2%)**: The car's engine is running so the car pushes against the truck, but the truck's engine is not running, so the truck does not push against the car **5(0%)**: Neither the car, nor the truck exert any force on each other.
	Sub-Question 2: **If the engine of the truck were running, the answer to the above question… (circle the correct statement)** **1(58%)**: would not change. **2(30%)**: would change depending upon the gear in which the truck's engine is running. **3(8%)**: would change, and the force exerted by the truck would be greater than that of the car. **4(5%)**: would change, and the force exerted by the car would be greater than that of the truck.	**Sub-Question 2:** **If the engine of the truck were running, the answer to the above question… (circle the correct statement)** **1(46%)**: would not change. **2(35%)**: would change depending upon the gear in which the truck's engine is running. **3(7%)**: would change, and the force exerted by the truck would be greater than that of the car. **4(5%)**: would change, and the force exerted by the car would be greater than that of the truck.

FIGURE 1

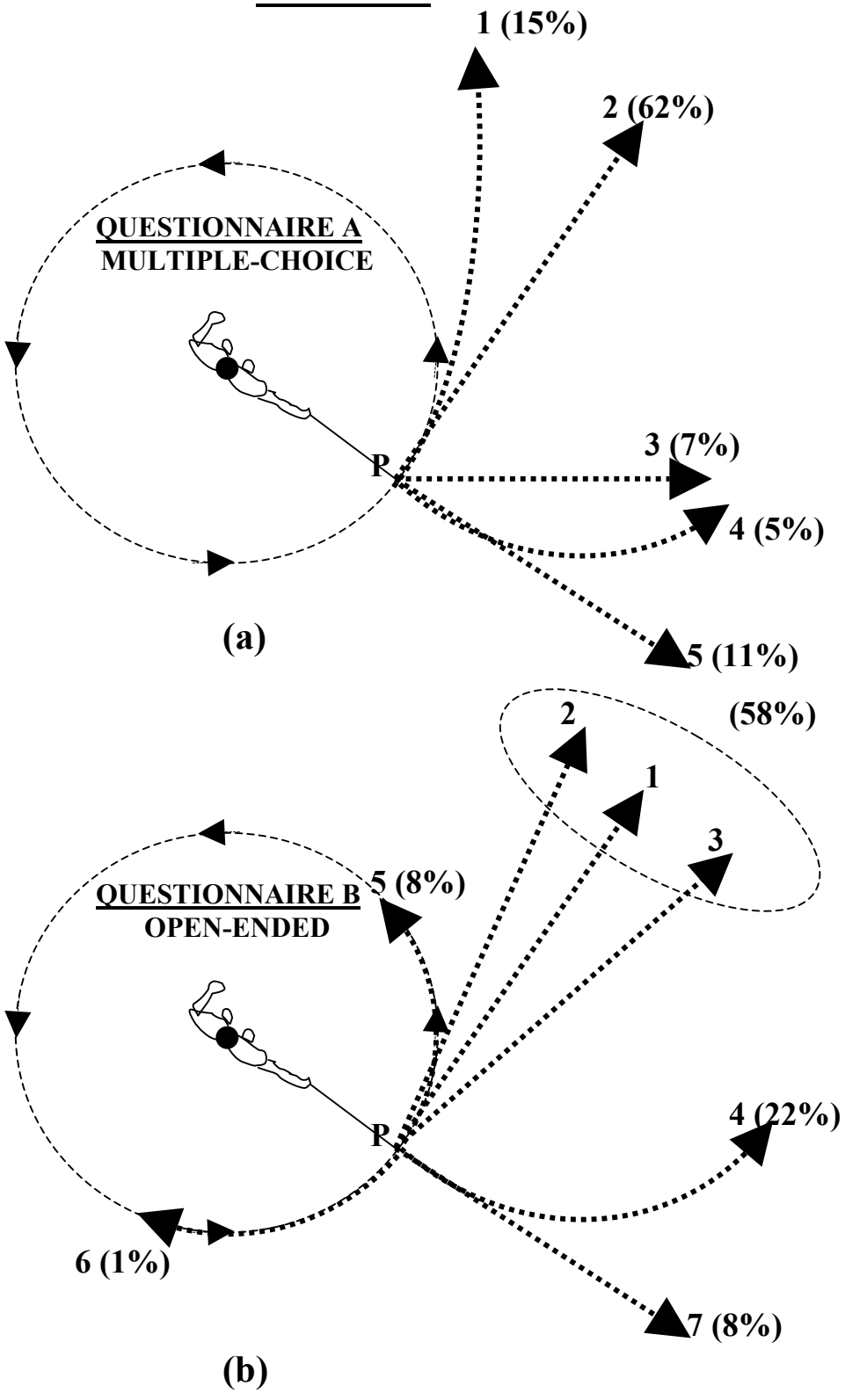
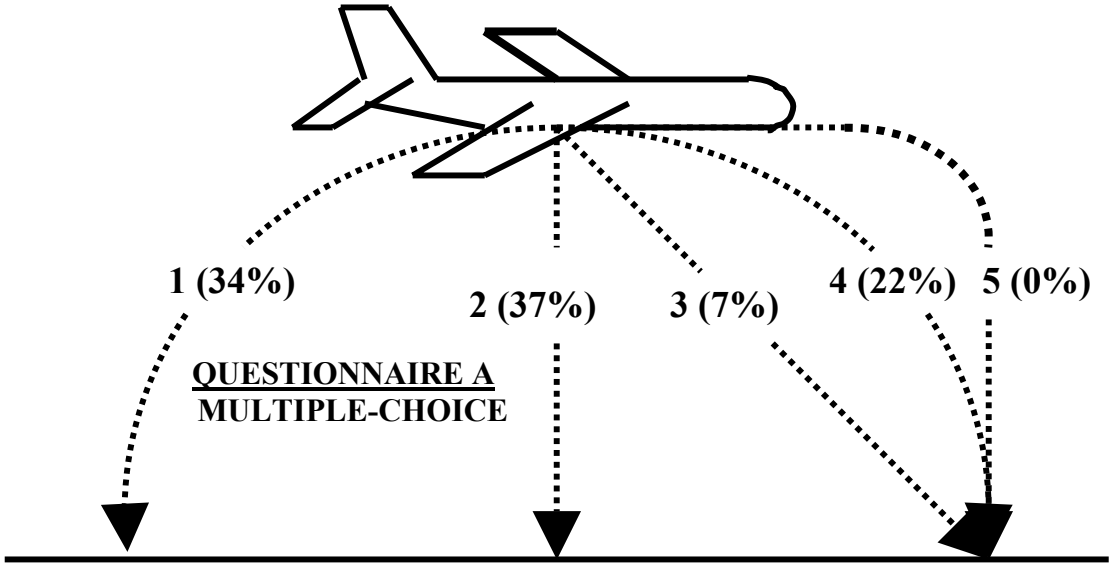
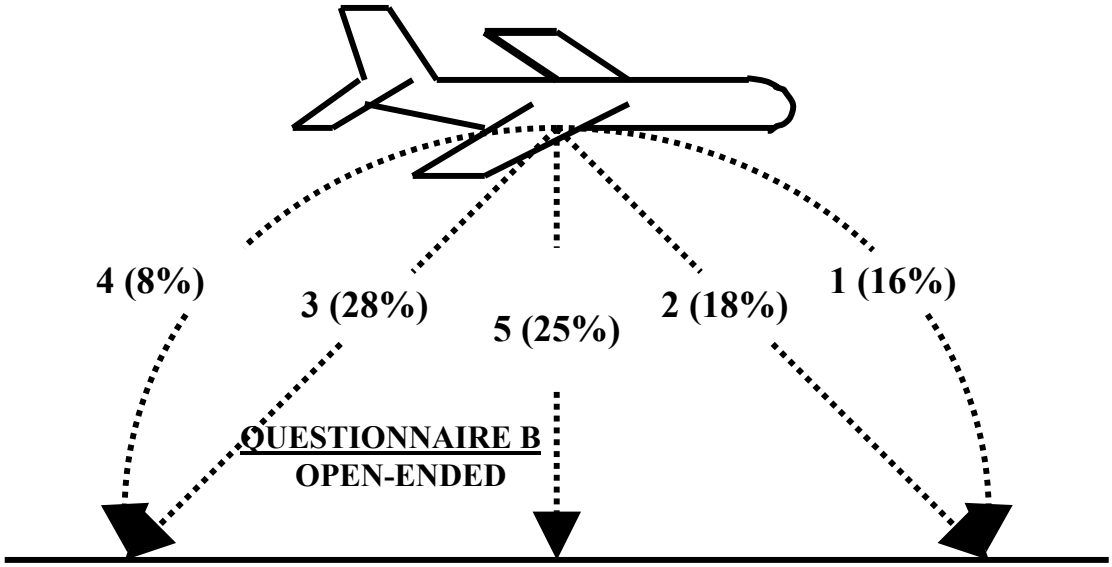

1 (15%)
2 (62%)
QUESTIONNAIRE A
MULTIPLE-CHOICE
P
3 (7%)
4 (5%)
5 (11%)
(a)
2
(58%)
1
3
5 (8%)
QUESTIONNAIRE B
OPEN-ENDED
P
4 (22%)
6 (1%)
7 (8%)
(b)

FIGURE 2


1 (34%)
2 (37%)
3 (7%)
4 (22%)
5 (0%)
QUESTIONNAIRE A
MULTIPLE-CHOICE

(a)


4 (8%)
3 (28%)
5 (25%)
2 (18%)
1 (16%)
QUESTIONNAIRE B
OPEN-ENDED

(b)

FIGURE 3

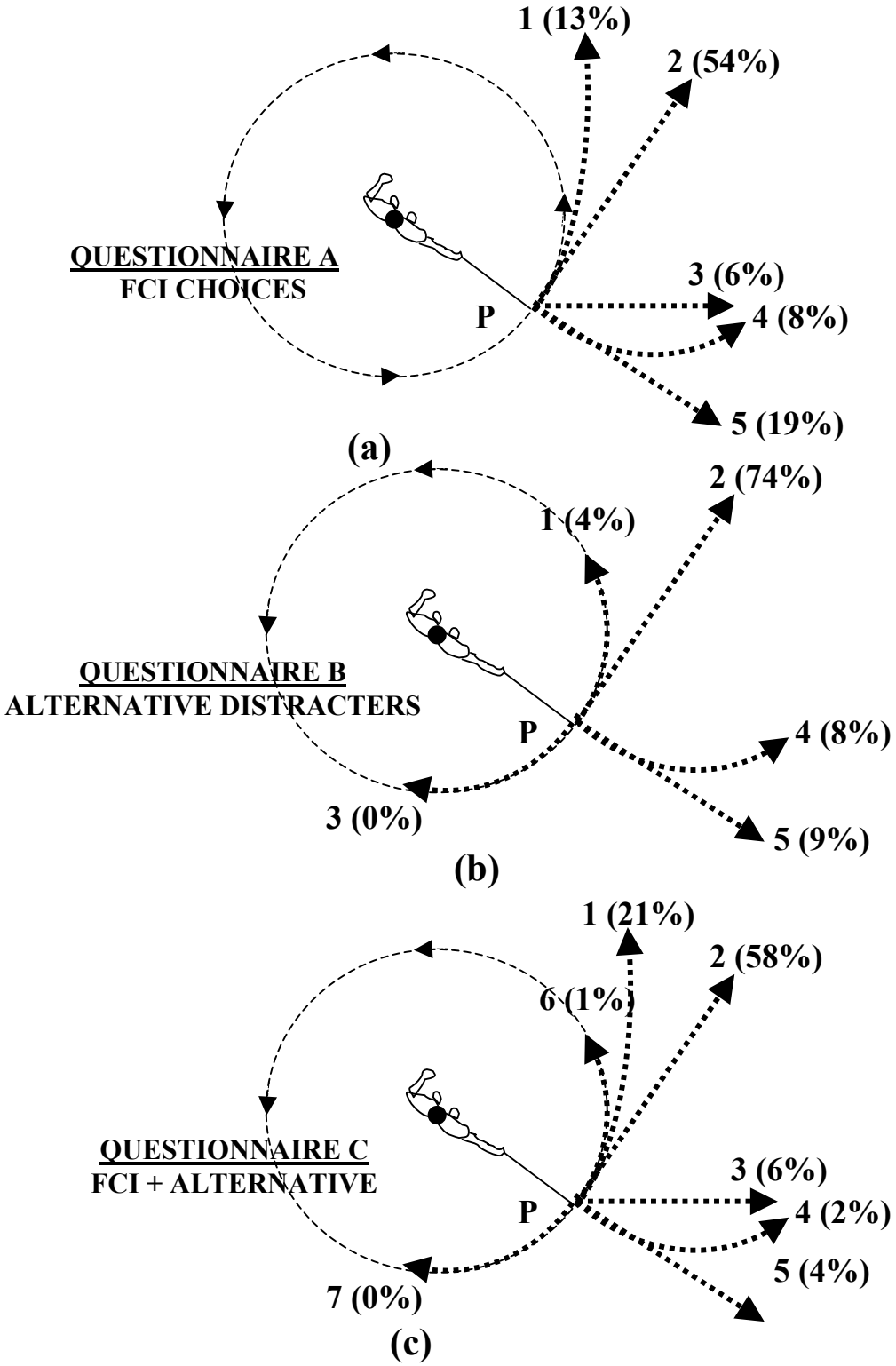
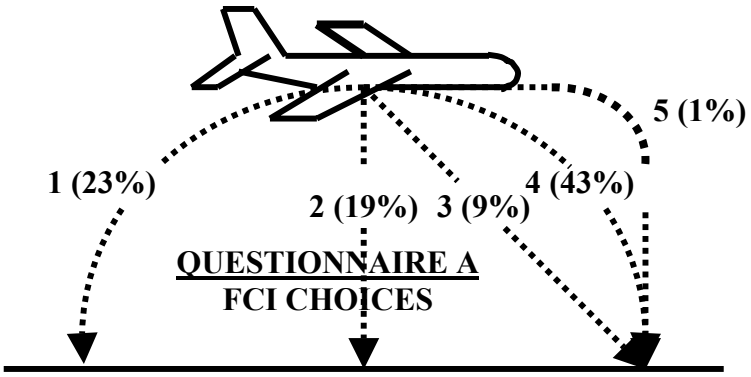
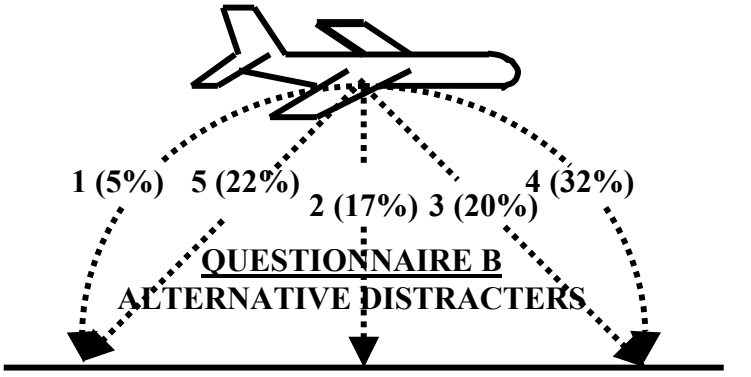

1 (13%)
2 (54%)
QUESTIONNAIRE A
FCI CHOICES
3 (6%)
P
4 (8%)
5 (19%)
(a)
2 (74%)
1 (4%)
QUESTIONNAIRE B
ALTERNATIVE DISTRACTERS
P
4 (8%)
3 (0%)
5 (9%)
(b)
1 (21%)
2 (58%)
6 (1%)
QUESTIONNAIRE C
FCI + ALTERNATIVE
3 (6%)
P
4 (2%)
5 (4%)
7 (0%)
(c)

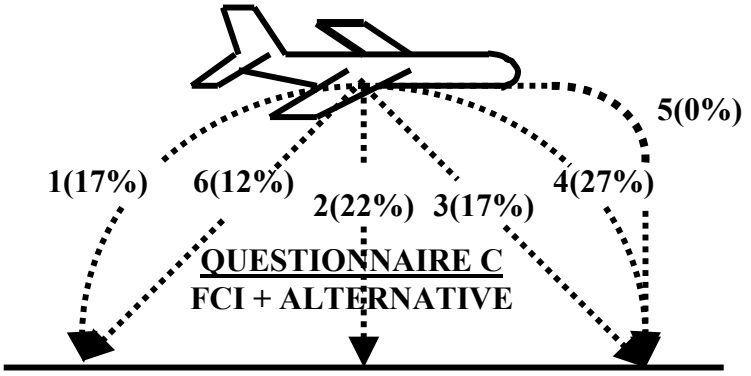
FIGURE 4


5 (1%)
1 (23%)
4 (43%)
2 (19%)
3 (9%)
QUESTIONNAIRE A
FCI CHOICES

(a)


1 (5%)
5 (22%)
4 (32%)
2 (17%)
3 (20%)
QUESTIONNAIRE B
ALTERNATIVE DISTRACTERS

(b)


5(0%)
1(17%)
6(12%)
4(27%)
2(22%)
3(17%)
QUESTIONNAIRE C
FCI + ALTERNATIVE

(c)

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