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When we presented the precession movement of a gyroscope in the classroom, we found evidence that some students also treated it as an equilibrium situation. Thus we started a systematic data collection with the purpose of finding alternative conceptions about the gyroscope behaviour.

The gyroscope precession, with its axis moving on an horizontal plane, occurs if there is an initial non-zero angular momentum; otherwise it will fall. Since the torque exerted by the earth's gravitational force is perpendicular to the angular momentum, it will not lead to a variation of the modulus, but will lead to a variation of the direction of the spin angular momentum. The gyroscope does not fall: it precesses because the spin angular momentum is always on the horizontal plane. This is so because the torque stays in this plane, just like the direction of the variation of the spin angular momentum.

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GYROSCOPE: ALTERNATIVE CONCEPTIONS FROM UNIVERSITY STUDENTS

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INTRODUCTION

In a research about circular motion (KRAPAS-TEIXEIRA and QUEIROZ, 1991) we observed that it is treated by the students as an equilibrium situation. That means, it is governed by Newton's first law (without, however, the use of non-inertial reference frames).

When we presented the precession movement of a gyroscope in the classroom, we found evidence that some students also treated it as an equilibrium situation. Thus we started a systematic data collection with the purpose of finding alternative conceptions about the gyroscope behaviour.

The gyroscope precession, with its axis moving on an horizontal plane, occurs if there is an initial non-zero angular momentum; otherwise it will fall. Since the torque exerted by the earth's gravitational force is perpendicular to the angular momentum, it will not lead to a variation of the modulus, but will lead to a variation of the direction of the spin angular momentum. The gyroscope does not fall: it precesses because the spin angular momentum is always on the horizontal plane. This is so because the torque stays in this plane, just like the direction of the variation of the spin angular momentum.

As pointed out by TIPLER (1984) "*the verification that the body moves on an horizontal plane, instead of falling, is at first sight, surprising. We are very familiar to situations, as the fall of a bar, in which there is no* *initial angular momentum and the direction of its variation is the direction of the angular momentum itself.*" This angular momentum is acquired by the bar through the action of the gravitational torque. That is because when the initial angular momentum is zero the torque will change the modulus of the angular momentum.

The fall of a bar, free to rotate around a point, and the precession of the gyroscope, are both examples of rigid body rotation, and have analogous in the translation of a particle. It is interesting to note that this analogy is evidenced by TIPLER(1984) when he comments the motion of the moon around the earth: *"Why does the moon not fall to the earth and strike it? If the moon, with zero initial momentum, were released, the change in the momentum (from zero) would lead to a motion of the moon toward the earth. However the moon has an initial motion perpendicular to the vector radius from earth (thus perpendicular to the gravitational force); then the change in the momentum results in a deviation of the moon's motion from a straight line, such a motion being now circular. Thus, although d***p** *is always directed to the earth,* **p** *is tangential to the orbit".* (Our translation)

DATA COLLECTION

Data was obtained by means of individual interviews, carried out video-taped with sixteen students of the basic physics courses at the university. These students had recently undergone theoretical-experimental instruction about the dynamics of rigid bodies. The first part of the interview aimed at finding these students' conceptions concerning the gyroscope. The second part, with didactic purposes, attempted to study the mechanisms of conceptual change from the existing alternative conceptions (identified in the first part of the interview) to the ones of the rigid body dynamics. In this work we will analyze only the first part of the interviews.

The physical situation presented referred to the motion of a falling rock, of the moon around the earth and of the gyroscope that precesses on an horizontal plane. This last movement was shown to the students. Then the following questions were formulated:

-When we release a rock, why does it fall towards the earth?
-Why does the moon not fall?
-Why does the gyroscope not fall?

The second question was formulated only after the first one was answered, and so on.

RESULTS

The answer to the first question was consensual: the rock falls due to the earth's gravitational attraction.

In order to classify the answers to the other two questions, we developed categories, resulting from an ampliation of those used in previous work (KRAPAS-TEIXEIRA and QUEIROZ, 1991).

In this earlier work the findings show that, to explain the circular motion (CM), some students invented forces (centrifugal or centripetal) to treat it as a situation with stability, that is, as an equilibrium situation. This equilibrium was due to the cancellation of forces with equal moduli and opposite directions. The treatment given to CM is thus vectorial in the radial direction. A second kind of answer brought out the appearance of forces in the direction of the tangential movement. Here we can recognize the famous alternative conception that always puts a force in the direction of velocity (VIENNOT, 1979).

In the present work, the questions that focus on the moon's movement bring out answers of the two types above:

Type I: *"There is an attraction and at the same time a repulsion that does not allow the moon to go out of its orbit"* (student 9).

Type II: *"There is a force that makes it* (the moon) *to revolve, a tangential force"* (student 12).

Aware of the CM conception, we looked for answers analogous to I and II but now related to the gyroscope situation. We found type I answers when the students mention a force that **cancels** the weight or a torque that **cancels** the weight's torque. Some students do not even identify the origin of the force that cancels the weight, as shown in the following examples:

"There is the weight force here (center of mass). *At this point a paired force will act* (the student points with his finger to a line that starts in the center of mass and goes up)*"* (student 2).

Other students assign the origin of the force to the *"force"* (that is, the torque) applied by the interviewer when she puts the gyroscope disc in movement. Then the disc starts to rotate and everything is explained by an equilibrium between the applied *"force"* and the weight force:

"There is a weight force that will pull this body down. But on the other hand, there will be a torque of movement that will keep this body rotating, making a force directed upwards. What gives it stability, keeping it on the horizontal position, is this force that you applied, which ***cancels*** *the weight force"* (student 9).

"When you pull, at the moment you pull (the string) *this produces a force, a certain velocity. Since there is a velocity there will always be a contrary force that will prevent it from falling"* (student 10).

It is interesting to note that student 9 talks about torque of movement but uses the force concept to establish the equilibrium with the weight.

Another remark is that a torque is attributed to the rotational movement. In other words, everything that rotates has a torque given at the begining of the rotation by the applied force, and this torque is maintained in the body. This means that the rotational inertia of the body is not admitted; in the same way, it is difficult for the students to understand translational inertia (VIENNOT, 1979) and so it was for the scientists of other times (EVORA, 1988).

As an example of a torque that **cancels** the torque of the weight force, we have a student that, to explain the gyroscope movement, invents a torque. This torque has equal modulus and contrary direction to that of the bearing force **F** (instead of the weight force). After identifying correctly the torque of the force **F** the student says:

"The angular momentum is an invariant of the universe. Then, in a system where I have initially an angular momentum, it tends to become constant. When you produce a torque (of the force **F** bearing the gyroscope on the base) *what does it do? The torque will produce a variation in the angular momentum. Then, what will the system do? It will produce a contrary torque, precisely to compensate. So that the torque will be zero, and* **Lo** *will continue to be* **Lo** (student 8).

It is worth commenting that students that give answers of the type I concentrate on the fact that the gyroscope does not fall. They do not refer to its rotation movement around the vertical axis. To justify the stability on the horizontal plane, they focus only on the rotation of the gyroscope around its symmetry axis.

On the other hand, in the case of answers of the type II, the opposite happens. Now the students talk about a force tangential to the trajectory of the center of mass, on the horizontal plane, that is responsible for the movement. Once more we see the necessity of a force in the direction of the movement. This force **composed** with the weight avoids the fall of the gyroscope. As it happened in the type I answers, many times the origin of this force is not mentioned.

Some times this force in the direction of the movement is attributed to the *"force"* applied to start the gyroscope's movement, as we also found in type I answers. The difference is that, in type I, it served to cancel the weight. In type II, it serves to compensate, or to combine with the weight, since they are orthogonal to each other. An example will ilustrate these findings. An example will illustrate these findings:

"There is a weight force pointing down and there is another one (the student points with his finger to a direction tangential to the trajectory of the center of mass)*. This one of inertia.* (The student gesticulates as if he was starting the gyroscope). *You* (the interviewer) *are the one who pulls"* (student 1).

From this analysis we see that the students assign a direction to this *"force"*, applied to rotate the gyroscope. This direction depends on what they want to explain: the fact that the gyroscope does not fall simply because the resultant force upon it is zero (type I) or the fact that it does not fall precisely because it is rotating around a vertical axis (type II).

There is another kind of answer, identified as type III, that expresses the students' concern with the two facts above, taken simultaneously. Naturally this kind of answer has no similar in the case of the moon. An example:

"There is a weight acting... There is a torque that makes it (the gyroscope) *rotate* (around its symmetry axis) *and there is a torque that makes it rotate like this* (around the vertical axis)" (student 4).

Only one student does not see this situation as one of equilibrium. He uses correctly the weight's torque to explain the variation of the direction of the spin angular momentum.

The table below shows the distribution of answers, in percentages, according to each type of answer:

ANSWER	MOON	GYROSCOPE
TYPE I	31	57
TYPE II	25	13
TYPE III		7
CORRECT	25	7
ANOTHER OR NO ANSWER	19	19

Table 1: Percentage of students according to the types of answers

FINAL COMMENTS

This research on university students' alternative conceptions concerning the precession of the gyroscope opens new perspectives: a revision of our research on alternative conceptions concerning the CM, allowing for an ampliation of the categories of analysis.

Firstly, we would like to emphasize the appearance of a kind of rotational impetus, analogous to the translational impetus. It suggests a need to keep the force that gave rise to the movement in the body, and so denying the idea of inertia. It is interesting to note that even the students that have overcome this problem in a translation situation, answering correctly why the moon does not fall, present it in the case of the gyroscope.

An analogous persistence was found by GUIMARAES (1987): students that had shown they knew the law of inertia applied to one-dimensional and horizontal cases, came back to a non zero resultant force in the case of inclined directions. A previous study (KRAPAS-TEIXEIRA, 1989) explains such persistence by a regression to more primitive models, when the physical situations presented raise the degree of complexity.

Therefore, a convenient recommendation to the teachers would be: having certified themselves that their students have learned Newton's first law, they should not imagine that this learning will extend automatically to other contexts. Students' everyday experience, that tells them that forces are needed to maintain motion, is so strong that it frequently makes them give their explanations according to it.

It is worth recalling that a feature of the transition from aristotelian and medieval physics to newtonian physics concerns the appearence of concept of motion as a natural state of the bodies, with no need of a cause to maintain it.

Secondly, we may understand the type II answers as referring to a stability/equilibrium situation, such as the one in type I answers. In type I, the equilibrium is a result of the **cancellation** of opposite forces: vectorial equilibrium in the radial direction. In type II, it results from a **combination** of two forces perpendicular to each other: non vectorial equilibrium.

As we had previously investigated the CM dynamics at the historical and individual levels, so we did in the study of the precession of the gyroscope. The results of the historical research are being presented elsewhere in these Proceedings (QUEIROZ & KRAPAS-TEIXEIRA, 1993).

When we were studying the origins of the equations that govern the precession of rigid bodies, we found a curious evolution, unknown to many people. It starts in the antiquity with Hipparcus' astronomy, concerned with the measure of the spring and fall equinoxes precession.

This in turn led us to a small incursion in basic physics and astronomy textbooks, besides modern encyclopaedia. When these texts explain the precession of the earth's equinoxes (the earth, just like a gyroscope, rotates around its symmetry axis and precesses around another axis, inclined with respect to the first), they give arguments that, in some ways, resemble those of the students. For instance,

"The origin of the displacement of the fundamental planes (equator and ecliptic) is the attraction force, due to the moon and the sun, acting upon the excess of the earth's equatorial zone. The earth's equator is inclined, making an angle of 23^{o},5 with the plane of its orbit (ecliptic's obliquity). Those celestial bodies (moon and sun) which are near the ecliptic tend to eliminate the inclination of the earth's axis of rotation. On the other hand, the fast earth's rotation opposes this tendency, giving a great stability to its rotation axis. ***Combining*** *these two opposite forces results in a progressive displacement of the earth's axis, called precession"* (MIRADOR ENCYCLOPEDIA, 1990) (our translation).

"If it spins rapidly with its axis inclined to the vertical, then the ***combination*** *of the rapid rotation and the downward force of gravity yields a slow precession of the axis, the upper point of the axis describing a horinzontal circle while the angle from the vertical remains constant"* (WYATT, 1977).

Contrasting with the above explanations, we find a remarkably clear solution to the calculus of the precession of equinoxes, using the second fundamental equation of rigid body dynamics (NUSSENZVEIG, 1992).

It is also worth stating that we do not exclude the following possibility: that the great emphasis given to conservations during the teaching process induces conceptions that invoke the equilibrium stability of the gyroscope. Some students even mention angular momentum conservation in their explanations.

On the other hand, we must consider possible influences from the way questions were formulated. It seems that with the questions "why does the moon not fall?" and "why does the gyroscope not fall?", we are reinforcing the search for justifications of a stability. We intend, continuing this work, to extend the research to other students, but adding the following questions: "why does the moon rotate around the earth, without ever colliding with it?" and "why does the gyroscope remain on an horizontal plane when it rotates?"

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