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The invariance of the size of the image of one's own body in front of a flat mirror: why do so many students get this question wrong?[+ * Δ]

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Abstract

This study involved presenting a question to first-year university students entering a biology program, during the first class of an introductory Physics course taught remotely due to the pandemic. The question asked what one could do to see a larger portion of one's own body in a flat mirror. Approximately 90% of the students answered that this would be possible by moving either forward or backward, replicating a historical result obtained in a previous survey with more than 400 students. After activities designed to improve understanding of the topic, a self-assessment tool was applied in which students explained the origin of their initial responses and described their final understanding. Content analysis of the data led to the creation of initial and final categories for the explanations, as well as a transition matrix representing the shifts in understanding. Self-assessments revealed a diversity of interpretations of the situation, some of which aligned with findings from previous research. After the activities, nearly half of the students moved toward the correct answer, although several still expressed uncertainties about the result. Finally, implications for the teaching of geometric optics are presented.

Keywords: *Flat Mirrors, Student Ideas, Self-Assessment.*

[+] A invariância do tamanho da imagem do próprio corpo em frente a um espelho plano: por que tantos estudantes erram esta questão?

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I. Introduction

When we stand in front of a flat mirror, we always see an image of our body that appears the same size, regardless of the distance we are from the mirror. If the mirror is higher than half of our height and if it is placed at a suitable height[2], we will always be able to see our entire body. If the mirror is less than half our height, the fraction of our body that we can see will not change as we move closer to or further away from it. Anyway, flat mirrors always form images of the same size as the object. However, when students, even at university level, are asked whether this image increases or decreases when the distance to it varies, the vast majority say that there is a change in its size or in the fraction of our body that we can see.

In an attempt to understand the reasons for this high incidence, the self-assessments of university students of the initial responses to this question, hereinafter referred to as the SPIFM question, were analyzed[3]. After that, it was analyzed whether and how these ideas changed after carrying out some specific activities. The context was an introductory physics course developed remotely (due to the COVID-19 pandemic) for newcomers to the biology program at a private university in southern Brazil.

In this group, the percentage of correct answers was very low, with only two correct answers among 44 students. Few believed that the size of the image formed by a flat mirror is independent of the distance to it. Among those who answered the question incorrectly, most stated that it would be possible, moving backwards, to see more of one's own body. The option that approaching the mirror would make this possible was chosen by a much smaller number of subjects.

After applying this and other questions related to the introduction to geometric optics[4], these students experienced a teaching strategy aimed at promoting the evolution of their initial ideas. The approach emphasized recording and analyzing the learning process itself using a self-assessment tool. The activities developed seem to have contributed to a shift in students' understandings towards scientific knowledge consistent with the phenomenon under study. Even so, in the end, many students who claimed to have understood the question still expressed uncertainty about the correct answer.

The records produced by the students in the self-assessment tools helped to list possible explanations for how the SPIFM situation was conceived and understood. The initial explanations seem to be related to the perspective from which distant objects are seen as appearing smaller. They are also related to aspects pointed out by other studies, such as the process of vision and light reflection. In the end, some implications are discussed for teaching

[2] If the lower edge of the mirror is too high, or if the mirror is higher than half the person's height and lower than their height (for example ¾ of the person's height), and the top edge of the mirror is too low (below the person's eye line), they will not be able to see their entire body.

[3] Size of a Person's Image in a Flat Mirror

[4] Hereafter, the word "optics" is considered to refer to geometric optics, excluding physical optics.

optics, especially flat mirrors, which, as this and other studies indicate, seem to involve considerable complexity.

II. Background

II.1 Other applications of the SPIFM issue

This section presents and discusses data from some applications of the SPIFM question. Table 1, below, summarizes the characteristics of the respondents and the data from six applications, in which the vast majority were college students. The first three refer to the data collected by Goldberg and McDermott (1986), and the other applications were carried out by the author of this study.

The table highlights how rare it is to choose the correct answer (6% on average), which is to say that nothing can be done in this situation to be able to see a greater part of one's own body. Furthermore, the option of increasing the size of the image by moving away from the mirror is much more popular (84%) than the alternative of moving closer (10%). Another important observation is that, despite having already studied the subject in higher education, it does not appear to influence the response.

The work of Goldberg and McDermott (1986), involving applications of the SPIFM question, is one of the most cited works in terms of research on students' ideas about optics[5]. The authors created a questionnaire with four questions about images in flat mirrors and administered it to three groups of physics students; of these, only one group had already studied optics in higher education.

The first group was interviewed with the authors proposing the questions so that the interviewer and the student were seated in front of a mirror and, when appropriate, making use of objects related to the questions proposed. The second group answered the questions on paper during class. The authors state that, in this situation, they sought to replicate the context of an interview as much as possible, for example, by explaining the questions orally, but without interacting with the respondents. The third group was interviewed immediately after the studies on flat mirrors. The question asked: "What, if possible, can you do to see more of your own body in the mirror?"[6]. The first three rows of Table 1 show the data for these three applications. The average success rate of these groups was approximately 10%. Moving backwards was the response of approximately 80% of respondents.

[5] Among the surveys on students' ideas consulted, this article is cited in almost 70% of them.

[6] "What, if anything, can you do to see more of yourself in the mirror?"

Table 1 – Applications of the SPIFM Question.

Year	N	Course(s)	Type and location of institution	n	Education Previous	Answer		
						Nothin g.	Walk away	Move closer
1986	S	Physics	private (USA)	35*	No	2 (6%)	33	0
1986	S	Physics	private (USA)	163	No	17 (10%)	129	17
1986	S	Physics	private (USA)	18*	Yes	3 (2%)	15	0
1988	S	Engineering	private (RS)	94	Yes	1 (1%)	82	11
1989	M	Tech. Chemistry	public (RS)	56	No	2 (4%)	50	4
2018	S	Engineering	private (RS)	28	No	0	22	6
2019	S	Engineering	private (RS)	31	No	0	24	7
Total				425	-	25 (6%)	355 (84%)	45 (10%)

* Data collected from interviews

Key: N: level of education (S: Higher; M: Medium); n: number of subjects. Source: Harres (2024).

Fig. 1 shows the diagrams constructed by the authors to represent the point of view of the interviewed students who predicted that it would be possible to see a larger part of their own body moving away from the mirror. Fig.1a represents the thinking indicated by students who seemed to conceive of the situation as if they were "looking at" the mirror with a fixed viewing angle. According to the authors, Fig. 1b and 1c schematically present the idea that the mirror "contains" the image.

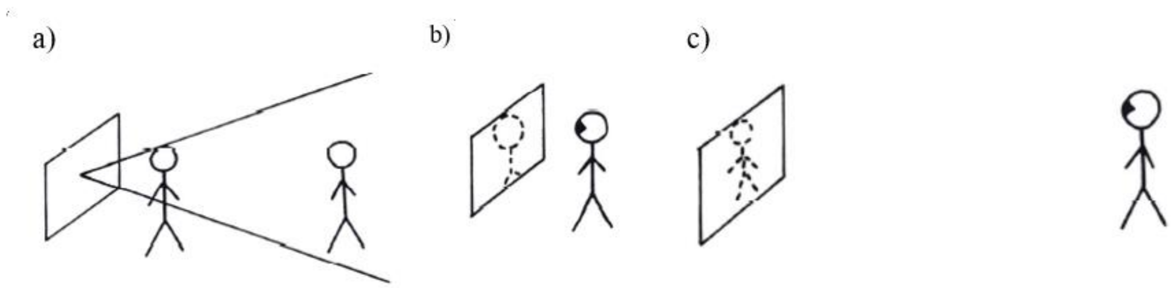

Fig. 1 – Diagram representing the answers to the SPIFM question. Source: Goldberg and McDermott (1986, p.478).

From the interviews, it became clear to the researchers that the students' responses were based on how they perceived their everyday experience, for example,

> *"... So if I'm here, you can only see part of me. But if I move back so my whole body is within the angle, you´re going to see my whole body" or "... As I go further away, my image becomes smaller and is able to fit into the mirror; but as I get close, my image becomes is much larger, and the mirror is a fixed size."* (Goldberg; Mcdermott, 1986, p.478).

During the interviews, none of the students constructed a ray diagram that allowed them to determine which part of their own body could be seen at different distances. Many have attempted to draw a diagram that would prove them correct. When asked about their level of confidence in their prediction, most students were convinced that it was possible to see more of their own body moving away from the mirror.

Following the applications of the SPIFM question, the fourth and fifth rows of Table 1 show data obtained by the author in two different applications, but in the context of the same research. In the first (Harres, 1993), the test was administered to a group of third-semester engineering students who had already studied optics at this level of education. Only one student out of 94 got it right. In another application (Harres, 1991), the SPIFM question was administered before instruction to students enrolled in the third year of the Technical Chemistry course taught by the author. As can be seen in Table 1, once again, the accuracy rate was very low, at 4% for this group.

Fast-forwarding 30 years, the fifth and sixth rows of Table 1 show two more recent applications (2018 and 2019), in which a reduced version of the same test, containing only eight questions, including the SPIFM question, was administered to third-semester engineering students as they began a course in optics and modern physics. In these two applications, no one got the question right. In both cases, after application, activities developed in the aforementioned research were proposed (Harres, 1991). The simplest of these activities consisted of bringing a mirror into the room in which the person could not see the entire body. The students were organized in a line and, standing in front of the mirror, each one approached to mark how far they could see, then moved away and approached again to check if their vision had changed. After these remarks, expressions of astonishment and intrigue were noted. Many students were not convinced and stated that they would check the results at home, insisting on their initial answers.

Concluding this review of the application of the SPIFM question, it is possible to affirm that, given the frequency and consistency of the data found over time, we are probably dealing with a question that is relevant to the teaching of optics and, at the same time, intriguing for studies on the learning of the concepts involved, which brings us back to the research carried out on the subject.

II.2 Students' ideas about flat mirrors

In Brazil, few publications analyze learning about image formation in flat mirrors, and studies specifically related to the SPIFM issue are even scarcer. For example, Goulart, Dias, and Barros (1989) interviewed 80 children aged between 7 and 10 years and identified (among other topics related to optics) that only 10% of them located the image of an object “behind” the mirror. More recently, Gircoreano and Pacca (2001) concluded that students have great difficulty in conceiving images, possibly due to the geometric description of concepts being done on a plane (on a blackboard or on paper), thus disregarding the spatial issue and other geometric entities involved in the formalism of the laws of reflection. On the other hand, Valadares and Fonseca (2004) observed strong resistance from the group that had experienced traditional teaching in overcoming the idea that, to see one's entire body, it is necessary that the mirror be at least the same size as the person. In the group that participated in the investigative proposal, this overcoming reached 90%.

Publications outside Brazil on image formation in flat mirrors are also rare. As in the Brazilian context, few address the SPIFM issue directly. Langley, Ronen, and Eylon (1997) identified that, even after a supposedly innovative teaching, few students between 14 and 16 years old were able to produce consistent explanatory diagrams for image formation. According to these Israeli authors, the sketches tended to be more pictorial and illustrative than symbolic and explanatory. Only four out of 140 students correctly explained the situation involving lightning.

Along the same lines, Chen Lin and Lin (2002) found that only 34% of 317 Korean students aged 15-17 responded that the position and image size of an object does not depend on the location of the observer. The study by Aydin, Keles, and Hasiloglu (2012), which interviewed 70 future science teachers in Turkey, found that the observer's position influences the size of the image.

In another study, Cummings and Grillo (2005) interviewed 50 American students in an introductory physics college course to better understand some gaps in the work of Goldberg and McDermott (1986)[7]. Among their findings, they noted that almost half expressed equality of the angle of incidence with the angle of reflection only in the speech and not in the drawings. Osuna, Torregrosa, and Carrascosa (2007) administered a questionnaire to 242 Spanish students aged 13 and 19 years old who had already received instruction on the subject. No student correctly located where the image is formed in a flat mirror. For the authors, these students did not have a physical representation of what an image is.

In the same direction, Hisik (2011) administered a test with questions on optics to 22 university students before and after implementing the innovative teaching proposal. The students' previous responses revealed that they differentiated between observing the image and its formation. And although there was an increase in the correct answers from students after

[7] Analyzed in the next section

teaching, many students continued to hold the ideas they had in the pre-test. The author concludes that the study of flat mirrors requires consideration of the existence of an observer, since the human eye is an inseparable component of explanations for flat mirror issues.

Also in the last decade, John, Molepo, and Chirwa (2016) investigated how 70 South African students aged between 15 and 17 conceived the reflection of light in flat mirrors. As noted in other works, most students did not seem to understand the role of the observer and the light source in image formation. The authors emphasize the need for discussions on ray diagrams in the process of image formation in mirrors, including the observer and the light source.

Recently, Husin (2019), based on the work of Goldberg and McDermott (1986), sought to understand the experiences of five university students regarding the formation of images by a flat mirror. The qualitative analyses developed by this author indicated that the students' experiences influence them to favor the idea that moving toward the mirror increases the size of the image, and moving away from it, the size of the image reduces. It was also identified the idea that the image of an object can only be seen entirely if the height of the mirror is greater than the height of the object. For this author, the teaching of optics should encourage students to consider the role played by the observer in the formation of images in all optical instruments, for example, by creating situations that allow them to test whether the observer's movement actually affects the image formed.

More recently, Degirmenci (2023) developed a questionnaire with 15 questions addressing the learning difficulties identified in his review of 18 articles on the subject and applied it to a group of 36 future early childhood teachers in Turkey, half of whom had already studied optics at university. Question No. 6 of this questionnaire practically replicates the SPIFM question. Only six subjects gave the correct answer.[8]

In the review of works on flat mirrors, it is also necessary to consider the consistent and extensive production on the difficulties of learning optics by the group of Argentine researchers formed by Marta Pesa and collaborators. Advancing previous research, the investigations of this group encompassed theoretical perspectives associated with the conceptual change model and the parallelism between the history of science and genetic epistemology (Pesa; Cudmani; Bravo, 1995). Although they investigated various aspects of optics, such as the propagation of light, the process of vision and image formation, no records were found of studies specifically addressing the SPIFM issue. Even so, it is worth highlighting some conclusions of this research related to this work.

This group of researchers was guided by three hypotheses about the students' prior ideas regarding the nature and propagation of light. The first is that these are structural and profound ideas in this area. The second is that, in general, the ways of thinking associated with these ideas constitute an obstacle to learning scientific ideas, justifying the need to identify

[8] The author did not report the distribution of responses between the options of distancing oneself and getting closer.

them. And the third is that the formulation of strategies to promote the learning of scientific ideas must involve, at the same time, methodological, epistemological, and attitudinal aspects (Pesa; Cudmani; Sandoval, 1993).

From the same group, the work by Sandoval and Salinas (2016) discusses and proposes actions for the issue of the supposed inversion of images formed by flat mirrors. According to the authors, observing images formed by flat mirrors has been part of daily life since early childhood, enabling the construction of specific knowledge with these and other optical instruments. Thus, considering that the study of the laws of light reflection and its application to flat mirrors is part of the teaching programs, the difficulties with the supposed inversion of images do not seem to be caused by a lack of knowledge, but rather by the misunderstanding of the role that the observer plays as part of the optical system and as a reference for observation. According to the authors, this misunderstanding "transforms the laws of optics into a set of techniques (construction of geometric diagrams and calculations of the position of image formation) without greater physical significance and relation to real situations" (p.36). This would have the consequence of attributing to flat mirrors effects produced by the actions performed by the observer or by changes in the reference system.

The researchers conclude that students between the ages of 12 and 15 tend to explain the formation and vision of an optical image based on intuitive ideas or other products of schooling that are generally incomplete and incorrect in terms of what is proposed by science. In many cases, students ignore the active role of the observer in image formation and claim, for example, that if the observer closes their eyes, the image will remain in the mirror, although they cannot see it, thus conceiving formation and vision as independent processes (Pesa, 1999; Bravo; Pesa; Rocha, 2011; 2012).

Taking into account the various works of this Argentine group, the previously reviewed works, and, in particular, the recent review by Degirmenci (2023), it is possible to compile a list of ideas (shown in Table 1) based on their relationship with the SPIFM issue that oppose or hinder the learning about image formation in flat mirrors.

Table 1 – Relationship between the ideas about images in flat mirrors and the SPIFM Question.

Relation	Possible student ideas
Indirect	The rays that form the image come from the observer's eyes.
	The image exists even if no observer is looking at it.
	When light hits the mirror, it remains on its surface.
	The image of an object in a flat mirror is directly in front of the observer.
	In a flat mirror, the image of the object is in front of/on the surface of or inside the mirror.
	The size of the image depends on the size of the mirror
	The distances from the object and its image to the flat mirror are different.
	If the dimensions of the flat mirror are increased, the image becomes larger.
	When the observer moves sideways, the image of the object moves in the opposite direction.
Direct	If the observer moves, the size and location of the object's image change.

	If a person moves closer to or further away from the flat mirror, they can see more of themselves.
	For an observer in a given position to see their entire body, the mirror must be at least at the same height as the observer.
	The fraction of one's body that an observer can see in a mirror whose height is less than half the observer's height varies depending on the distance between the observer and the mirror.

Source: Harres (2024).

III. Application of the SPIFM issue and subsequent activities

The application of the SPIFM question analyzed here had a similar result to the previous applications reported in section II.1. Of the 44 respondents, only two (4%) chose the correct option and of the remaining 42, 82% chose the "move away" option.

However, the context of this application was quite different from the last two listed in Table 1. Firstly, whereas previously they were students attending their third physics course (60h) in engineering programs, now the class consisted of newcomers to higher education studying Biology (teaching and bachelor's degrees) whose curriculum included only one 30-hour physics course, which was scheduled to be taught in fifteen two-hour evening classes. The class consisted of 51 students, 72% of whom were female.

Second, the start of the academic semester (end of February) coincided with the onset of the COVID pandemic, resulting in remote learning for all weekly classes except the first class. During the synchronous meetings, which were not mandatory, Zoom was used to broadcast and record the classes. The recorded classes could be watched at any time (asynchronously), and the respective assignments could also be submitted at any time.

Based on previous research (Harres; Guedes, 2018), the course was organized according to an approach that starts with students' ideas about the topics to be studied and then proposes individual and collective activities structured in didactic strategies with greater potential for the promotion of conceptual evolution, as proposed by Hashweh (1996). From this perspective, the actions of explaining, convincing, refuting, and developing students' ideas are in ascending order of this potential, respectively.

The assessment of learning, although guided by accepted scientific knowledge, focused on self-assessment to encourage the most spontaneous expression of thought possible. In this sense, the conceptual evolution achieved was unrelated to the assignment of grades, which was conditional on the completion of tasks, especially the self-assessment process of activities. At the end of the semester, no one failed[9].

At the first meeting, a shortened version of eight questions of the aforementioned test built by the author was administered (Harres, 1993). The overall average number of correct answers was 2.5 questions (31%). Of the 44 respondents, 40 students obtained an average score between one and four correct answers, out of a total of eight possible. Two students got all the

[9] A complete analysis of the development of this proposal in remote format is presented in Harres (2024).

questions wrong. The highest score was five correct answers, achieved by two students. Finally, a predictable picture, as shown by the review of research in the field.

In the following classes, each of the test questions was discussed. For each of them, the distribution of the class responses among the options was initially presented, followed by an analysis and discussion of the assumptions that would have led the students to choose each alternative. While each question of the test was discussed, students were encouraged to express their opinions, and images, videos and live experimental demonstrations of the correct answer were presented, providing students with the information to help them reflect on their initial answers to the test.

For instance, Fig. 2 shows photographs of the setup presented to students in the discussion of the SPIFM question using two batteries as objects and a small mirror resting on a wooden block. After placing one battery in front of the mirror, a second battery is placed in the direction and next to where the image of the first one is seen until they are seen with the same size. After that, it is possible to measure the distance from each one to the mirror. As shown in Fig. 2a, 2b, and 2c, these distances (approximately 8.0 cm) are equal. The Fig. 2d shows the same assembly 4.0 cm away from the batteries, to the mirror.

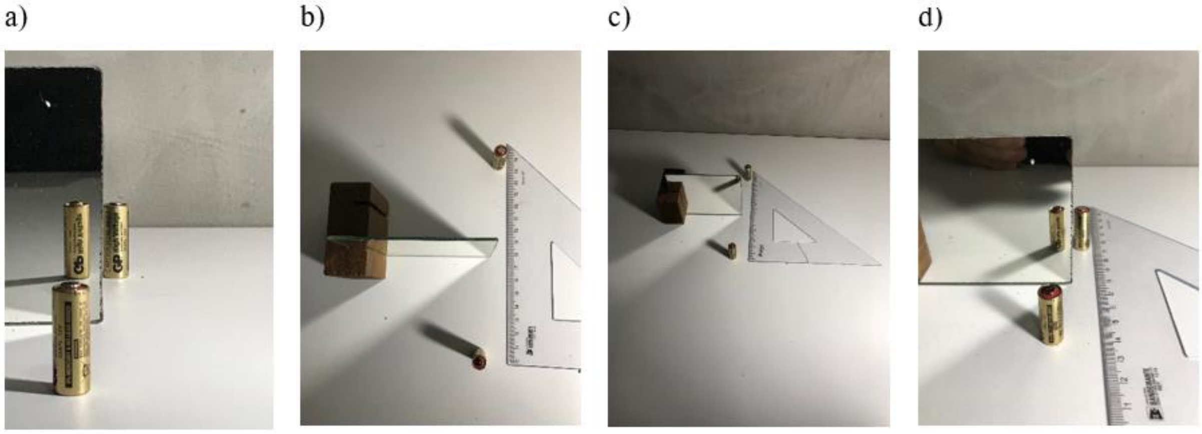

Fig. 2 – Setup with batteries in front of a flat mirror showing that the distance between the object *and the mirror is the same as the distance between its image and the mirror. Source: Harres (2024).*

Considering that the notion of perspective may influence the incorrect answers to the SPIFM question, resources were sought to help identify this notion. Thus, one of the activities was to analyze the images shown in figures taken from Cassidy (1981) and Epstein and Hewitt (1981).

a) b) c)

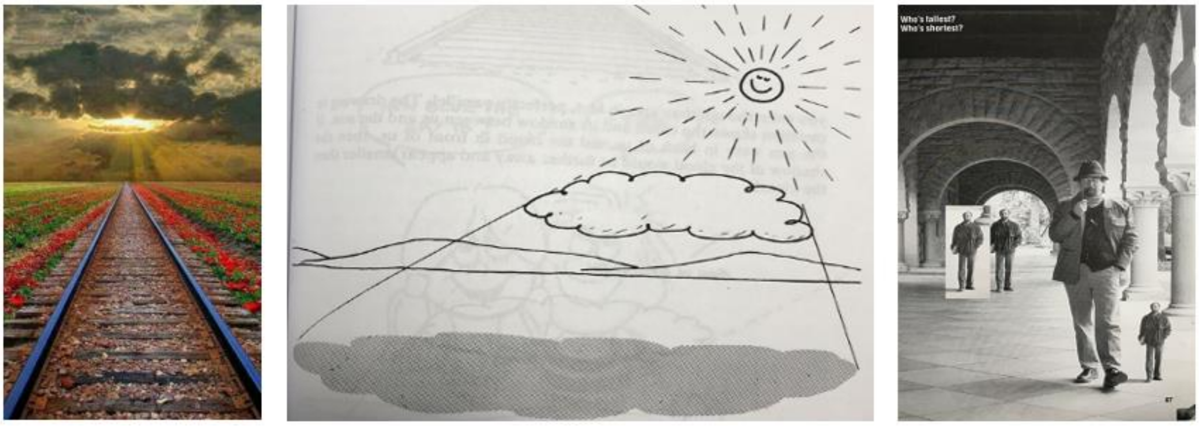

Fig. 3 – Images about perspective. Source (a) and (c): Cassidy (1981, p.86 and 87); (b): Epstein; Hewitt (1981, p. 265)

In the photograph in Fig. 3a, it seems that the tracks will meet at a distant point, and in this illusion, the distance between them and their size appear to decrease. At that moment, it was asked what would be found if we measured the distance between the tracks where the photograph was taken and then measured far ahead in a very distant place. In the photograph in Fig. 3c, although it may not appear so, the small human figure that appears in the lower right corner is the same size as the one in the background of the photo, which can be verified by placing a copy of this image next to the one in the background, as the author has done.

Regarding the perspective, the situation shown in Fig. 3b is about the size of clouds that cast shadows on the ground. This image tends to lead the observer to think that these shadows are larger than the cloud that originated them. Again, being able to measure the size of the cloud and the size of the shadows, we would observe that they are equal. Furthermore, these authors draw attention to the less common fact that if the Sun is behind us and the clouds in front of us, we would see a shadow that appeared smaller than the clouds, as can be seen, for example, from an airplane.

Next, it was emphasized that it was very important for each person to test the answer to the SPIFM question for themselves in front of a mirror. Thus, students were asked to *take selfies* at home at two different distances. Initially, many did not perform in a way that would provide the proposed comparison. Many used a mirror in which it was already possible to see their entire body. Others changed the position of the body or cell phone in relation to their own body, making it impossible to properly compare the fraction pf the body shown in each of the two positions. Others used mirrors that did not allow for significant variation in the distance to it. In all these cases, the students retook the photos.

To assist in this task, the author took photos of himself at two different distances from a mirror, as shown in Fig. 4a and 4b, below, and which were subsequently published in the virtual environment of the subject. The photograph in Figure 4c, on the right, shows the enlarged photograph 4b for a better comparison with the one taken closer to the mirror. Looking at the two photos, it is noted that the body part shown is the same; that is, in both photos, you can only see up to the waist (at the end of the shirt).

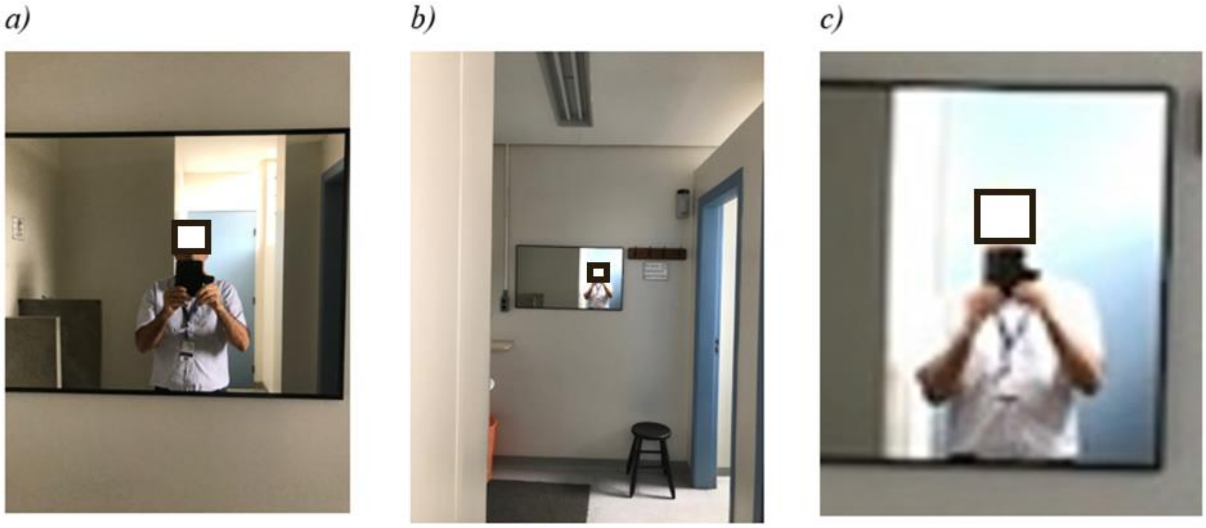

Fig. 4 – Selfies taken *by the author at two distances from a flat mirror (4a and 4b). The Fig. 4c magnifies part of the image of 4b. Source: Harres (2024).*

As an example of this process carried out by the students, as Fig. 5a and 5b show *selfies* taken by a student. Fig. 5b, the author used the same process as the previous figure, enlarging the most distant photo to facilitate comparison. This enlargement was made on each of the photos received and sent to all students with an opinion on the matter.

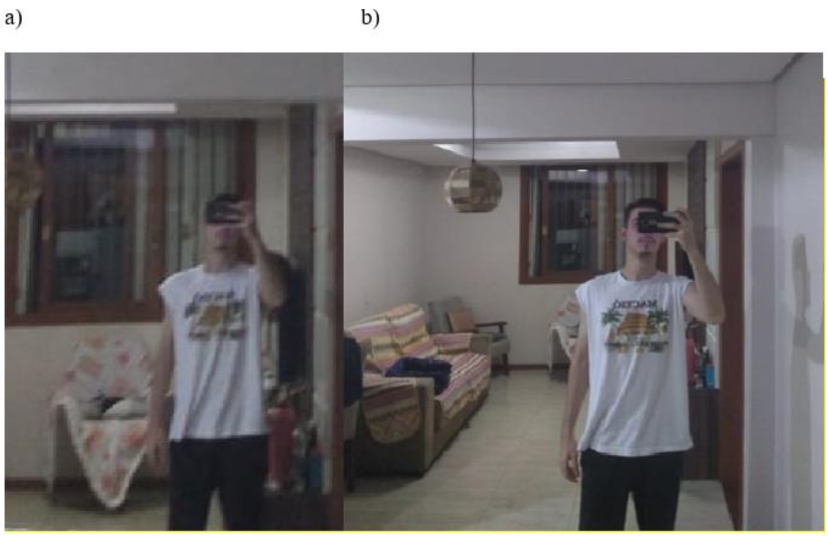

Fig. 5 – Example *of a selfie at two different distances. Source: Harres (2024)*

IV. Analysis of self-assessments

After taking the test in the first class and discussing each of the eight questions on the test in the following two classes, the time had come for the first self-assessment. In this first self-assessment, students received a document in which, for each question (especially those they had answered incorrectly), they had to justify the chosen option and try to express the thought behind it after the activities. The following subsections detail the analysis of the justifications for initial thinking and understanding after the first activities related to the SPIFM question.

During this process, there were many revisions until most students were able to express their initial self-assessment more clearly and deeply. The initial responses in the self-assessment tool revealed little about the implicit thinking behind the choice of answer for each question, even though the written responses were extensive, with an average of 25 words per justification.

As a final moment of self-assessment, after studying other topics in optics, they were asked (in the 8th week of class) how confident they were in this idea and how *selfies* had helped in this process. Chart 2 summarizes the questions of each self-assessment moment.

Chart 2 – Questions of the self-assessment of the SPIFM question at each moment.

4th lesson (about the 1st)	**4th class**	**8th class**
What did I think when I answered in the first class**?**	What do I think now after the activities?	After the completion of the first bimester, evaluate: a) How confident are you today in your understanding? b) What influence did *selfies* have on this (possible) change?

Source: Harres (2024).

The following subsections analyze these self-assessments. Responses to the self-assessment tools were categorized according to the Content Analysis proposed by Moraes (1999). In this process, we sought to map the reasons pointed out by students regarding the difficulties with this issue and how adequate or inadequate understandings were perceived by them. This led to the development of some hypotheses regarding the origin of these ideas and the identification of obstacles to the acceptance of the correct idea. For the analysis, only the responses of those subjects who completed all tasks related to the SPIFM question (44 students) were considered.

IV.1 First part of the Self-Assessment: What did I think when I answered on the first day of class?

At this point, 42 initial justifications were analyzed since the two students who answered the question correctly did not justify their answers. Among the others, the diversity of responses stood out, even though, in many cases, different words were used to refer to the same aspect of the situation. As already shown in Table 1, the frequency of choosing between the alternatives "move away" and "move closer" was quite uneven, 36 and 6, respectively. For the answer “move away”, the analyses led to the construction of seven categories. Similar justifications were gathered in the same category. Even so, it was possible to identify some central ideas, distinct in some categories, as shown in Table 3, which summarizes the results of this analysis.

Table 3 – Categorization and frequency of justifications for "moving away" responses (n = 36).

Category	n	Central Ideas	Example
11 - You see more moving away	11	You can see more from a distance.	*If we are too close to the mirror, we can only see the part of it we look at* (E40[10]*).*
12 - Daily practice	11	Everyday practice. Personal Experience Real situation in front of a mirror. Common sense.	*I remembered all the time when I was getting ready to go out and, in order to see my whole body, I would step away from the mirror* (E4).
13 - Increases image size	5	Increases reflected body area. The image is more complete.	*By moving away from the mirror, I would have access to a larger area that was being reflected by the mirror* (E43).
14 - Field of view increases	4	Widen the field of vision. Increases the area seen by the mirror. Next to the mirror, we only see the part of it that we look at	*I thought of a full-length mirror, which increases the area seen by the mirror the further I move backward* (E13).
15 - Other ideas	5	If I lean over, I can see the entire body. It depends on the size of the mirror. Completely random scene.	*The question did not specify the size of the mirror, so when I read it, I thought of a mirror that would reflect my entire body* (E5).

Source: Harres (2024).

The content of the justifications given by those who chose option "c" (moving closer to see a larger fraction of their own body) was categorized as shown in Table 4.

[10] The number next to the letter identifies the student's code.

Table 4 – Categorization and frequency of justifications for the response's "approach" (n=6).

Categories	n	Example of answers
15 - Other ideas	2	*You decrease in relation to the mirror* (E16). *I thought of a medium-sized mirror and that if a person stood in front of it, they would be able to see their torso* (E40).
16 – Zoom Effect	4	*I thought that as we got closer, we would see our image "zoomed in" and then see more of my body* (E19).

Source: Harres (2024).

IV.2 Second part of the Self-Assessment: "What do I think now after the 3rd class?"

At the same time as the previous self-assessment, students should try to express how they felt after completing the activities. In contrast to the previous question, at that point, the students expressed the source of their ideas in greater depth. As a result, the analysis focused on the degree and quality of the understanding expressed. Table 5 shows the categories constructed, their frequency and some examples.

Among the responses to the second self-assessment, approximately 65% expressed adequate or advanced understanding, including only one of the two subjects who had initially answered the question correctly. The other person who had answered correctly did not respond to this self-assessment, explaining that he already had a prior understanding of the question.

Table 5 – Categorization and frequency of understandings in the second moment (n=44).

What do I think now?	n	Examples
Advanced understanding	20	*I understand that, in fact, moving does not change the size of the generated image. To see your entire body, a mirror that is half your height is sufficient. Secondly, the person must be completely upright (E35).*
21- Adequate understanding	9	*Even if I move backward or forward, the size of what I can see does not change* (E5).
Understanding the size required to see the entire body	10	*I could see that a mirror half our height is enough to see the entire body* (E43).
No change of mind	3	*I think the same* (E19).
24 - Other understandings	2	*What I understand now is that this thinking does not apply to "unconventional" mirrors, since the same thing does not happen* (E28). *Reading the correct answer to the question that should not be asked to see a larger part of your body, I still do not understand how this is possible* (E15).

Source: Harres (2024).

Based on the information for the categorizations at the two moments, a cross-tabulation table was constructed showing the frequency of the transition of the understandings expressed at these two moments (Table 2). The final understanding achieved does not seem to be related to the initial ideas since advanced and adequate understandings were distributed proportionally equally among the different initial ideas of the subjects. At the same time, three subjects expressed the same initial positioning. Of these, two students had previously marked option "b" (move away) and one marked option "c" (move closer).

Table 2 – Frequency of transitions between initial and final categories.

Initial Response (n)	**Categories Final** / **Categories Initial**	**20 - Advanced**	**21 - Adequate**	**22- Full-length mirror size[11]**	**23 - Unchanged**	**24 - Other understandings**	**Total**
Nothing (2)	10 - Nothing can be done		1	1			2
Move away (36)	11 - You see yourself more moving further away	5	1	2	2	1	11
	12 - Daily practice	6	3	2			11
	13- Enlarge the image	2	2	1			5
	14 - Field of view increases	2	1	1			4
	15 - Other ideas	3	1	1			5
Move closer (6)					1	1	2
	16 – Zoom Effect	2		2			4
Total		**20**	**9**	**10**	**3**	**2**	**44**

Source: Author (2024)

IV.3 Third part of the Self-Assessment: "How confident am I in the correct answer?" and "How did *selfies* influence that?"

The third question of the second self-assessment tool asked about the degree of confidence in the understanding achieved. Among those who expressed an advanced understanding (23 subjects), two of them did not indicate a high or complete level of confidence, as stated by the student below:

Sometimes, I still think that going backwards, I will be able to see more of my own body because it is already part of my daily routine and, thus, it has become an automatic thought (E29).

[11] Two of these subjects also demonstrated an adequate understanding of the SPIFM question

Of the eight students who expressed adequate understanding, three indicated a medium level of confidence.

Well understood, even though everyday life tries to show the opposite (E11).

I still don't feel very confident, because although the question makes sense in practice, the theory still leaves me a little confused, so much so that I can't explain this issue with a more concrete and elaborate explanation (E39).

The last question of the second self-assessment tool attempted to identify the possible influence of taking *selfies* on the comprehension process. From the responses, we identified an attribution of relevance to the taking of these photos, of which we highlight some examples:

It influenced me to realize that my empirical experiences were distorted, and that I should not base my knowledge on them (E22).

Before taking selfies, I didn't understand this issue at all. I was sure that moving away from the mirror, I would see more of my body reflected. With them, I was able to see and understand. Great influence (E27).

It was the factor that made me change and understand the phenomenon. Only with practice could I see that the image did not change. Mainly because of the details in the photos, which did not become larger when brought closer to the mirror, only clearer and more visible (E33).

V. Discussion and implications for teaching

The first conclusion of this analysis, already confirmed by the historical data, is that the SPIFM issue is not trivial for students. Although the application analyzed here showed that after the activities, there was a considerable shift toward the correct answer, a significant degree of mistrust remains, even among those who claim to have understood the topic. There is also a continuing understanding that the issue concerns the minimum size that a flat mirror must have for us to see our entire body.

One possible explanation for this influence may be the fact that many textbooks present the geometric and, in some cases, algebraic demonstration of the minimum size of a mirror for a person to see their entire body, as shown in Figure 6b below. At the same time, it seems plausible that students remember this conclusion even when they have poor mastery, as the review showed, in the use of the laws of reflection and in the construction of ray diagrams to locate and establish the size of images. This statement seems to corroborate the fact that among the previous ideas of the students, whether they had studied optics before or not, the most prominent is that a mirror must be equal to or greater than the person for them to see their entire body.

Furthermore, without disregarding factors related to possible shortcomings in teaching and the influence of adversities arising from the context of remote classes, which was unprecedented for everyone involved in the midst of the pandemic, it is possible to list other aspects that contribute to the high error rate in the SPIFM question and to the resistance to accepting the correct answer.

Firstly, it seems that reflection on everyday experience does not help. When someone approaches a mirror, they imagine that they see themselves “larger”, as if there were a “zoom”, when, in fact, they see themselves in greater detail because the distance between them and their image decreases. On the other hand, in mirrors large enough to see one's entire body, the person steps back, leading them to the thought that, perhaps due to perspective, their image changes in size, when in fact, only the distance between the person and the image has increased, allowing them to see themselves in context. The combination of these two situations may explain why some people initially say that the fraction of the body that can be seen increases both when moving away from and approaching the mirror.

Another aspect that does not favor constructing the correct answer is the fact that many everyday mirrors are less than half our height (usually located in bathrooms). Moreover, these mirrors rarely allow for a large variation in proximity so that the part of the body shown does not change. Mirrors fixed to walls or wardrobe doors, on the other hand, are generally high enough to allow you to see your whole body, regardless of the distance from the mirror.

There is also the fact that the SPIFM question also involves basic concepts, such as the process of vision, the concept of light rays, the laws of reflection, and the process of image formation, whose difficulties, as shown by the review, are not negligible. For Goldberg and McDermott (1986), when moving away from the mirror in general, the subject neglects the corresponding decrease in apparent size in the mirror and the fact that the decrease is proportionally the same for the mirror and the image.

These authors present a diagram (Figure 6a) that serves to show the fraction of one's body that can be seen in a flat mirror in a given position. By changing the position of the person "O" and reconstructing the diagram of the boundary rays of the person's size, it could be shown in image "I" that the observed fraction does not change. However, there is rarely space (literally) in textbooks to perform this construction at two different distances[12]. In books and teaching materials on the subject, what is often found is geometric or algebraic analysis demonstrating that in a flat mirror with half the height of a person, as shown in Fig. 6b, in which the height “x” of the mirror is equal to half the height “H”, allows the person to see their entire body.

[12] In Harres (1991), this situation is presented by asking students to trace the behavior of the boundary rays starting from the body of a person placed in front of a flat mirror at two different distances.

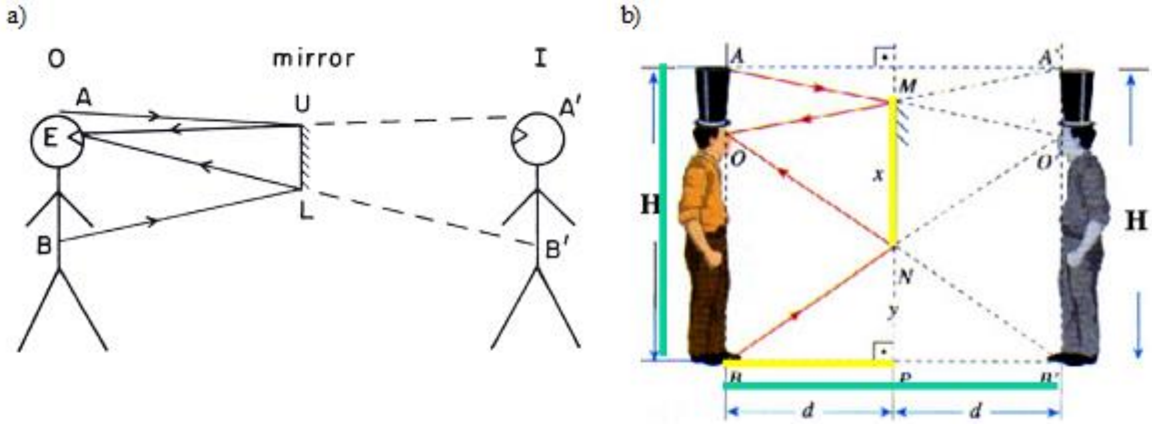

Fig. 6a – Formation of the image seen by the person himself in front of mirrors of different heights. Source Figure *6a: Goldberg and McDermott (1986, p.478).*

Fig. 6b: *Geometric demonstration to see yourself full body in a flat mirror. (*www.prevest.com.br/dados/editor/file/AULA_02_E_03_ESPELHOS_PLANOS.pdf. Access on: 05 set. 2024*).*

Similarly, Gürel and Eryilmaz (2013) analyzed nine physics textbooks commonly used around the world as well as the physics textbook recommended by the Turkish Ministry of Education. Based on a documentary analysis, these authors found that eight of the ten books analyzed either ignore the role of the observer's eye or do not specifically emphasize it in image formation or the observation process. According to the authors, these representations, which are very common in textbooks, can lead students to form the mistaken idea that the presence and location of the observer's eye are necessary for the process of observing images, but not for the process of forming them.

Maistegui, Chamorro, and Tisera (1998), concerned with the difficulties in learning optics, already pointed out that the teaching of the formation of images produced by mirrors (or lenses) is more geometric than physical. There is a striking recurrence in the construction of diagrams to geometrically locate the position of the image, and little attention is paid to looking and thinking about the "physical fact" of how the image is formed. The authors propose procedures to reduce "abuse in teaching optics and take advantage of the educational value of a more physical approach to teaching" (p. 136).

This complexity also reaches an epistemological dimension covering topics such as the role of the observer in the process, the question of the existence of the image in the mirror or in the student's mind ("Does it exist even when you are not looking in the mirror?"). All of this seems to contribute to the diversity of views presented by students in explaining their own thinking, even reaching the dichotomy between what is thought and what is perceived. In other words, there is a dichotomy between reflective practice and everyday practice, which may also explain the degree of mistrust of correct answers even by students who expressed adequate understandings (Sandoval; Salinas, 2016).

Still regarding the role of the observer in the process, it is worth considering what Silveira (2016) states about the process of image formation in our retina when answering a question in the CREF[13] very similar to the SPIFM question. For this author, the size of these images depends on the distance between this object (virtual image conjugate to the mirror) and our eye. As Figures 7a and 7b show, the further away we are from the mirror, the smaller the image on our retina will be, as shown in the diagram above. Therefore, when we move away from the mirror, we see ourselves getting smaller, even though the image in the mirror remains the same size. And Silveira (2016) adds:

> *What we see are images on our retina! We never see images other than those that occur on our retina, exciting our photoreceptors. When we stand in front of a flat mirror, the virtual image formed by the mirror (Fig. 7c) is the same size as our body. This virtual image is a real object to our eyes.*

a) b) c)

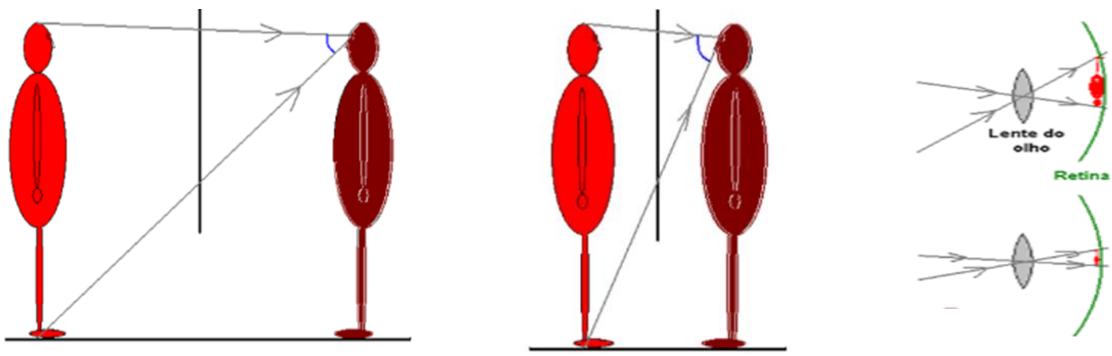

Fig. 7 – Diagrams of the formation of the image of one's own body on the observer's retina at two different distances from the mirror. Source: Silveira (2016).

As for the implications of this work for physics teaching, it should be emphasized beforehand that it is difficult for students of any level to deal with light rays, the process of vision, and image formation, even in the case of the simplest optical instrument, which is the flat mirror. Table 6 lists the main ideas arising from this research and from the review of other studies that have the potential to promote learning about flat mirrors.

Table 6 – Ten implications for teaching

1	Initially, assess the availability or otherwise of a light representation scheme and an image concept consistent with the scientific model.
2	Keep in mind that even college students may not understand the nature and mechanism of image formation through light reflection.
3	Emphasize the light source and the presence of the observer in the drawings.

[13] Centro de Referência no Ensino de Física da UFRGS (https://www.if.ufrgs.br/cref/hp/index.htm).

4	Encourage students to consider the role played by the observer in the formation of images in all optical instruments.
5	Consider the human eye as an inseparable component of explanations.
6	Care must be taken when using the expression “reflection in the mirror” due to the different interpretations that may arise from it.
7	Be aware that the representations found in textbooks may lead students to believe that the presence and location of the observer's eye are necessary for the process of observing images, but not for the process of learning.
8	Create situations that allow verifying that the movement of the observer does not alter the size or position of the image.
9	Encourage the connection between thought and phenomena to occur, when appropriate, as a result of a reconstruction of prior knowledge.
10	Structure teaching based on students' initial ideas and encourage self-assessment.

Source: Harres (2024).

Unfortunately, the more common classroom approach devotes too much space to the geometric aspect at the expense of a more physical study of the images. Analysis of the perspective from which we view the reality around us also seems to be rare. According to Viennot (2002), teachers are generally insensitive to perceptions resulting from specific characteristics of images used in teaching, disregarding “how misleading a pictorial message can be in a field such as elementary optics” (p. 328).

From the perspective of the knowledge produced in this study, it is important to acknowledge some limitations of the investigative process. For example, even though the analysis followed the chronological order of the self-assessments, in practice, the students did not complete the tasks simultaneously, hindering a more “instantaneous” view of the evolution of their understanding. Another aspect worth mentioning is that the novelty of the approach experienced by the students may have encouraged concealment when completing the tasks, although the intensity and quality of the written interaction, as recorded in the self-assessment tools, point in another direction.

Despite these limitations, some aspects inherent to the didactic approach seem to have contributed positively to the advancement in the quality of understanding as well as awareness and clarity of thought itself, even when an adequate understanding has not been achieved. In another study, which analyzes the entire process experienced in this discipline with the same group of students (Harres, 2024), the insistence on explaining their initial ideas was highly valued by them, since each one had to make an effort to reflect on what they thought when they first answered the questions and what they came to think later.

Finally, it is expected that this work will contribute to broadening the scope and depth with which flat mirrors are addressed in physics teaching and that, in this process, students' ideas will be considered in contrast to the complexity of many situations studied in geometric optics, as is the case with the SPIFM question.

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