

Article

Exploring Pre-Service Teachers' Conceptual Understanding and Confidence in Geometrical Optics: A Focus on Gender and Prior Course Achievement

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Abstract: This study investigated pre-service science teachers' conceptual understanding and confidence in geometrical optics with respect to gender and their previous achievement in geometrical optics course. A total of 189 (60% female and 40% male) pre-service science teachers who had completed geometrical optics course in state universities in Turkey participated in this study. The conceptual test instrument consisted of 20 items taken from the first tier of the Four-Tier Geometrical Optics Test (FTGOT) developed by the researcher, followed by a self-reported measure of teachers' confidence in the accuracy of their responses. The interest and experience scores were obtained through scales previously developed by the researcher, and these two variables were used as covariates in the analysis. The two-way between-groups ANCOVA tests were conducted to answer the research questions. The results showed that male pre-service teachers tend to have slightly higher conceptual understanding and confidence scores in geometrical optics than females with medium effect sizes while controlling for geometrical optics experience and interest scores. The findings were discussed, and implications for research in geometrical optics were provided.

Keywords: geometrical optics; confidence; conceptual understanding; gender differences; interest; experience



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1. Introduction

While vision is one of our vital senses and our experience with light begins at birth, previous studies have shown that individuals have severe difficulty in comprehending geometrical optics even after formal instruction at school. Therefore, studies in conceptual understanding in geometrical optics have attracted the interest of researchers in different countries from early childhood to university level [1–8]. Thorough research has indicated that many pre-service and in-service teachers hold the same difficulties as their students. Experience in teaching a physics topic, such as geometrical optics, does not necessarily lead to developing a conceptual understanding. A large gap often exists between what is taught and what is learnt in physics at all levels of instruction [9]. There is ample evidence that teachers do not fully conceptualize geometrical optics, and difficulties related to the topic are robust and consistent with respect to age, prior instruction, ability, gender, culture, or nationality [5,10–14]. In the domain of geometrical optics, previous studies have mainly focused on four interrelated groups of topics. They include vision (the role of the observer's eye, how humans see), the nature and propagation of light (properties of light, rectilinear propagation of light, illumination, shadows), optical imaging (i.e., plane mirrors, spherical mirrors, lenses, prisms), and color. The scientific conclusions from these studies indicated that individuals find the subject (i.e., geometrical optics) perplexing and difficult to comprehend, leading them to form solid and inappropriate understandings that resist change. Furthermore, it has been discovered that several personal and demographic features, such as gender, achievement scores in related courses, attitude, beliefs, and

motivation, are influential on conceptual understanding in optics [15–17]. However, the number of studies in those respects is still scarce.

One's ability to assess one's own knowledge and decisions is considered an important skill in educational endeavors. Confidence is an essential metacognitive construct that concerns the self-assessment of one's own knowledge. The use of confidence has been common in social sciences, especially in the field of psychology, since the 1970s. Recently, confidence studies have been conducted in science education as well. Carefully evaluating their own understanding prior to making a decision is described as desired habits of mind and skills in educational research [18]. As a result of instruction, individuals are expected to improve their ability to assess their performance, besides moving from naïve conceptions to the conceptions compatible with scientific models [19,20]. In general, conceptual understanding is thought to be related to both correctly answering a question and recognizing the correctness of the answer at a metacognitive level [21,22]. Hence, self-rated confidence judgments have recently been much included in traditional concept inventories in physics education, measuring the conceptual understanding of different topics [23–27]. Confidence has been found to have a positive correlation with academic achievement and motivation [28–30]. Research in this field has revealed that individual differences in academic performance, gender, age, personality, ability, or even the nature of the testing instrument influence confidence [28,31–33]. For instance, women were found to be less confident than men in their abilities in science, and this gender difference increases with age [28,34–36].

Several studies have documented gender differences in science achievement, attitude, interest, experience, and self-concept across many countries and over time [37–40]. In conceptual understanding, this gender gap is mostly found to increase as students proceed through grade levels, and the gender disparity is especially prominent in physics compared to other science disciplines (chemistry and biology). Several projects (e.g., WISE-Women into Science and Engineering) have been developed to achieve gender parity and promote female participation, contribution, and success in science, but this gap is still present. Based on Madsen, McKagan, and Sayre's [41] analysis of 26 published articles comparing the impact of 30 factors that could potentially influence the gender gap, no single factor is found to be sufficient to explain the gender gap. According to the authors, the gender gap is most likely due to the combination of many factors rather than any one factor that can easily be revised. Girls' less and diverse kinds of experiences with and interest in science is said to be responsible for their low academic achievement in science. In biology and life sciences, girls' interest is as pronounced as in boys, while in physics, girls are usually found to have less interest than boys [41]. Gender differences in interests in science were also reported in projects such as ROSE and PISA. According to OECD [42], compared to similarly talented boys, high-performing girls reportedly tend to underestimate their own abilities.

However, other research has criticized that gender differences simply depend on the content and context of a topic [37,43,44]. Hasni and Potvin [45] stated that the differences in interests in science observed between boys and girls were generally non-significant or weak, while those concerning grade level were greater, such that interest was said to drop as grade level rises. According to Osborne and Collins [46], boys were more interested in the subject of forces, whilst girls were more interested in studying light and electricity. Both girls and boys were enthused by the topics related to space. In one of the current author's previous studies [44], female pre-service physics teachers were found to have slightly more experience than male pre-service teachers in geometrical optics, while no gender difference was found in their interest in geometrical optics. Optics, which includes aesthetic dimensions (e.g., rainbows and color), is one of the topics that is said to be equally appealing for both sexes [46,47]. Hoffman [48] asserted that the best indicator of a student's interest in physics is their self-concept regarding their confidence as capable performers. Gender differences in physics-related self-concept appear to be the key factor explaining

gender disparities in physics interest, and these differences have a more distinct impact on girls' than on boys' interest in physics.

Since the 1970s, psychology has extensively investigated the relationship between performance and confidence [33,49]. Up to now, however, few studies have been applied in physics [19,20,23–25,27,28,50–52]. Most of these studies have used confidence ratings and conceptual performance on specific topics to explore the strength of misconceptions in those specific physics topics. The question of whether gender and prior achievement levels differ in conceptual understanding and confidence in geometrical optics, however, remains a question in need of answering. Hence, this study investigated pre-service science teachers' conceptual understanding and confidence in geometrical optics with respect to gender and prior achievement levels in geometrical optics. Specifically, this study aimed to answer the following two research questions:

- RQ1. What are the impacts of “achievement level in geometrical optics course” and “gender” on pre-service science teachers' “conceptual understanding in geometrical optics” while controlling for their geometrical optics “experience” and “interest”?
- RQ2. What are the impacts of “achievement level in geometrical optics course” and “gender” on pre-service science teachers' “confidence in geometrical optics” while controlling for their geometrical optics “experience” and “interest”?

2. Methods

2.1. Participants and Procedures

Data for this study were collected by surveying 189 pre-service science teachers who had completed geometric optics course in state universities in Turkey. The sampling method was convenience sampling in terms of ease of access by the researcher. The participants consisted of 113 females (60%) and 76 males (40%). In Turkey, pre-service science teachers are selected and placed on one of the four-year undergraduate science education programs at Faculties of Education through a national university entrance exam. Each faculty has its own education program with some compulsory science courses, as well as pedagogical courses and pedagogical content knowledge courses that integrate subject matter and pedagogy. After the completion of their program, pre-service science teachers can be employed in elementary schools as science teachers. Pre-service science teachers take several physics courses (Physics I (mechanics), Physics II (electricity and magnetism), Physics III (thermodynamics and optics), and Physics IV (modern physics)) during their education at education faculties. Geometrical optics is discussed in the Physics III course, and pre-service teachers are expected to conceptualize some basic concepts regarding geometrical optics. The pre-service teachers in this study were in the fourth year of their teacher education programs, with an average age of 22. They completed the conceptual test (including questions in geometrical optics in the first tier and regarding confidence in the second tier) in forty minutes, and the interest and experience scales in ten minutes. Demographic information such as age, gender, and prior performance in the geometrical optics course was included in the conceptual test. The four-year undergraduate science teacher education programs all have geometrical optics as a compulsory course in their programs.

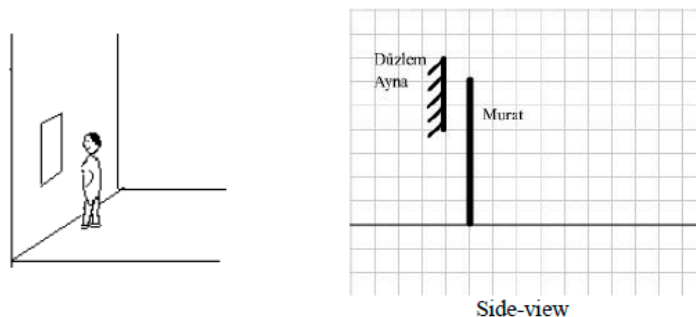
2.2. Measures

2.2.1. Conceptual Understanding in Geometrical Optics

Conceptual understanding of geometrical optics was measured using the first tier of the Four-Tier Geometrical Optics Test (FTGOT) developed by the researcher previously [25]. The FTGOT was a multiple-choice test specifically designed to assess misconceptions in geometrical optics with strong distractors. The first tier of a typical four-tier test is an ordinary multiple-choice test with its distractors addressing misconceptions. The second tier of the test asks for the confidence of the answer selected in the first tier. The third tier of the test asks for the reasoning for the answer in the first tier. The fourth tier asks for the confidence of the answer in the reasoning. A recent review study in geometrical optics

by Treagust and Zadnik [53] stated that FTGOT is the only optics test using quantitative data identified in the comprehensive review of research-based assessment instruments in physics and astronomy. In our previous study [25] special analysis for the identification of misconceptions in the topic was discussed in detail. It was reported that the FTGOT was a valid and reliable instrument in also assessing conceptual understanding in geometrical optics. In order to ensure the content validity of the test scores in the current study, the test items were examined in terms of the content and format (test directions, figures, and language) by experts in science education. The test instrument consisted of 20 items in geometrical optics in the contexts of plane mirrors (8 items), spherical mirrors (7 items), and lenses (5 items). In each test item, either “seeing/observing an image of oneself” or “seeing/observing an image of others” cases were questioned in one of these geometrical optics contexts. Nearly equal importance was given to the inclusion of the context-case combinations in the test. In the present study, the first tier of the FTGOT was used to measure the participants’ conceptual understanding of geometrical optics (see Figure 1). The correct answer given to the first tier of the test was coded as 1, and 0 otherwise. The participants’ total conceptual test scores (out of 20) were calculated by summing each correct answer given to the test items. The Cronbach’s alpha reliability of the test scores was calculated 0.61. The reliability of the tests with extremely easy or extremely difficult items would be low since the variability of the scores would be low [54]. With their specially constructed distractors, conceptual tests include rather difficult items that result in somewhat small reliabilities, as agreed in previous studies [23,55,56].

5.1. Murat is looking at his image in a plane mirror which is half of his body length and hanged on the wall that the bottom of the mirror is aligned with his breast as shown in the below figure on the left. On the right, you can see the side-view drawing of the same figure. So; what would Murat do in order to see his whole body at once?



- a) Come closer to the mirror.
- b) Go farther away from the mirror.
- c) Slides the plane mirror downward direction.
- d) Nothing.
- e) Other:.....

5.2. How confident are you in your answer for the above question?

- a) Absolutely sure. b) Sure. c) Not sure. d) Absolutely not sure.

Figure 1. Sample item from the FTGOT (including the first two tiers used in this study).

2.2.2. Confidence Score

Each of the ordinary multiple-choice items in the FTGOT (first tier) was followed by a self-reported measure of confidence of pre-service teachers in the accuracy of their responses (second tier). Pre-service teachers were asked to choose from “absolutely sure” to “absolutely not sure” on this second tier regarding their answers in the first tier (see Figure 1). If a participant was “absolutely sure” or “sure” about the answer in the first tier, it was coded as 1, and 0 otherwise. Thus, a confidence score out of 20 was calcu-

lated for each participant. The Cronbach's alpha reliability of the confidence scores was calculated 0.856.

2.2.3. Achievement Level in Geometrical Optics Course

The performance of pre-service teachers in their previously completed geometrical optics course was asked for as demographic information in the conceptual test as a 4.0 scale. For analysis, the course achievement performances were divided into three: "low-", "medium-", and "high-achieving" groups. Pre-service teachers' geometrical optics course grades were assigned as "high-achieving" if the geometrical optics course grade was ≥ 3.0 ; "medium-achieving" if $2.0 \leq$ geometrical optics course grade < 3.0 ; and "low achieving" if geometrical optics course grade < 2.0 . Out of 189 participants in the study, 55 were found to be in the low-achieving group, 67 were in the medium-achieving group, and 67 were in the high-achieving group.

2.2.4. Geometrical Optics Experience and Interest Scores

The Optics Interest and Experience Scale (OIES) previously developed by the researcher [44] was used for geometrical optics experience and interest scores. The four-point Likert-type scale comprised twenty-five items with two subscales as experience and interest. The experience scores of the participants were obtained from 14 corresponding items of the scale, while the interest scores were obtained from the rest, corresponding 11 items. The Cronbach's alpha reliability of the experience and interest scores were calculated 0.966 and 0.835, respectively. The geometrical optics experience and interest scores obtained for each participant were used as covariates from the current author's previous experience and the previously discussed related literature; these covariates (experience with and interest in geometrical optics) are thought to be influencing scores on the dependent variables (conceptual understanding and confidence in geometrical optics). Removing the variation in the dependent variables due to covariates, ANCOVA likely increases the power or sensitivity of the statistical tests [57].

2.3. Data Analysis

The two-way between-groups ANCOVA tests were used to answer two research questions. This technique allowed us to simultaneously test for the effect of each of our independent variables (Achievement level in geometrical optics course and Gender) on the dependent variable (Conceptual understanding in geometrical optics score and Confidence score, separately) while statistically controlling the effects of covariates (Interest and Experience scores) and also to identify any interaction effect. An interaction effect occurs when the effect of one independent variable on the dependent variable depends on the level of a second independent variable.

3. Results

In order to investigate RQ1, the two-way between-groups ANCOVA test was conducted in IBM SPSS.23. For the two-way between-groups ANCOVA test, preliminary checks were conducted to ensure that there was no violation of the assumptions of normality, linearity, homogeneity of variances, homogeneity of regression slopes, and reliable measurement of the covariates for the conceptual understanding in geometrical optics scores.

In the comparison of the conceptual understanding in geometrical optics scores according to achievement level in geometric optics course (low-, medium-, high-achieving) and gender, a statistically significant main effect for gender ($F [1, 181] = 11.955, p = 0.001$) was observed with a medium effect size (partial eta squared = 0.062). The main effect for achievement level in the geometrical optics course ($F [2, 181] = 0.05, p = 0.951$) and the interaction effect ($F [2, 181] = 0.289, p = 0.749$) did not reach statistical significance. The non-significant interaction effect indicates that there is no significant difference in the effect of achievement level in geometrical optics course on the total conceptual understanding

in geometrical optics scores for males and females. These results suggest that males and females differ in conceptual understanding in geometrical optics scores. Some descriptive statistics related to conceptual understanding in geometrical optics scores are illustrated in detail in Table 1. An inspection of the mean scores indicated that males showed higher scores ($M = 7.09$, $SD = 3.17$) in conceptual understanding of geometrical optics than females ($M = 5.65$, $SD = 2.56$), and this difference is practically medium because of the moderate effect size.

Table 1. Some descriptive statistics related to conceptual understanding in geometrical optics score according to gender and achievement levels in geometrical optics course.

Conceptual Understanding in Geometrical Optics Score	Gender	N	Mean	Std
Low Achieving Group (Optic Course Grade < 2.0)	female	23	5.91	2.50
	male	32	6.87	3.14
	Total	55	6.47	2.91
Medium Achieving Group ($2.0 \leq$ Optic Course Grade < 3.0)	female	48	5.62	2.51
	male	19	7.31	2.85
	Total	67	6.10	2.69
High Achieving Group (Optic Course Grade ≥ 3.0)	female	42	5.52	2.69
	male	25	7.20	3.53
	Total	67	6.15	3.12
Total	female	113	5.65	2.56
	male	76	7.09	3.17
	Total	189	6.23	2.90

In order to investigate RQ2, the two-way between-groups ANCOVA test was conducted as well. For the two-way between-groups ANCOVA test, preliminary checks were conducted to ensure that there was no violation of the assumptions of normality, linearity, homogeneity of variances, homogeneity of regression slopes, and reliable measurement of the covariates for the confidence scores.

In the comparison of the confidence scores according to achievement level in geometric optics course and gender, a statistically significant main effect for gender ($F [1, 181] = 10.319$, $p = 0.002$) was observed with a medium effect size (partial eta squared = 0.054). The main effect for achievement level in the geometric optics course ($F [2, 181] = 0.60$, $p = 0.55$) and the interaction effect ($F [2, 181] = 1.142$, $p = 0.322$) did not reach statistical significance. The non-significant interaction effect indicates that there is no significant difference in the effect of achievement level in the geometric optics course on total confidence scores for males and females. These results suggest that males and females differ in terms of their confidence scores. As shown in Table 2, males showed higher scores ($M = 14.49$, $SD = 3.86$) in confidence than females ($M = 12.21$, $SD = 4.77$). The effect size, which is an indication of practical significance, is medium because of the moderate effect size.

Table 2. Some descriptive statistics related to confidence score according to gender and achievement levels in geometrical optics course.

Confidence Score	Gender	N	Mean	Std
Low Achieving Group (Optic Course Grade < 2.0)	female	23	12.39	4.76
	male	32	13.47	4.13
	Total	55	13.02	4.39
Medium Achieving Group ($2.0 \leq$ Optic Course Grade < 3.0)	female	48	12.60	4.69
	male	19	15.53	3.63
	Total	67	13.43	4.58
High Achieving Group (Optic Course Grade $\geq$ 3.0)	female	42	11.67	4.93
	male	25	15.00	3.49
	Total	67	12.91	4.71
Total	female	113	12.21	4.77
	male	76	14.49	3.86
	Total	189	13.13	4.55

In summary, the results of the current study revealed that male pre-service teachers tend to have a slightly higher conceptual understanding of geometrical optics and confidence scores than females with medium effect sizes while controlling for geometrical optics experience and interest scores.

4. Discussion and Conclusions

This study aimed to investigate pre-service science teachers' conceptual understanding and confidence in geometrical optics with respect to gender and achievement levels according to a previously completed geometrical optics course. To increase the statistical power of the test, two covariates (i.e., experience and interest scores) that, according to theory and previous research significantly correlate with the dependent variables, were chosen. Based on the analysis conducted in the study, it was found that only gender affects pre-service teachers' conceptual understanding and confidence in geometrical optics, while their performance in previously completed geometrical optics course does not.

Research on gender differences has shown that males and females substantially differ with regard to making sense of physics. Males have been reported to achieve higher performance in tests and are more interested in, experienced with, and have confidence in physics than females [39,58,59]. Although biological differences between males and females' brain structures were considered among one of the explanations for gender difference in terms of performance, the mostly agreed-upon explanation was socio-cultural, such that the gender differences were caused by the cultural and social environment that individuals live in. Some other studies, however, have claimed this is due to females' interests, experience, and confidence in physics, that their learning outcomes are not consistent as a result [60,61], and that the reasons are topic- and context-specific [37,44,47,59]. Optics has been previously discussed as one of the topics in physics that may have been equally appealing to both males and females. However, the number of studies on gender differences in geometrical optics conceptual understanding is limited and needs further investigation.

Teachers' low conceptual knowledge of geometrical optics in this study is in keeping with the results reported in previous studies [11–13]. Even after many courses are taken, pre-service teachers still have deficiencies in their conceptual understanding of optics. Similar to the present study's results, Heywood [12] showed that primary trainee teachers experienced great trouble putting basic concepts about light and optical instruments into coherent explanations. Mumba, Mbewe, and Chabalengula [13] found that upper and lower elementary school teachers exhibited low conceptual knowledge of light concepts regardless of their experience in teaching. Studies examining teachers' conceptual understanding of optics according to gender are very scarce. In their study, Chu, Treagust, and

Chandrasegaran [15] investigated several variables (including grade level, gender, school science achievement level, and school district) affecting middle school and high school Korean students' basic optics conceptions and attitudes to science. All variables, except grade level, were found to influence students' conceptual understanding of optics and attitude to science, with school science achievement scores being the most effective. In this study, male students were found to show a better conceptual understanding of optics and a more positive attitude to science than female students. This is similar to the results of the current study. Furthermore, students with high school science achievements were found to have a better conceptual understanding of optics and attitude to science. However, in the current study, no difference was found in conceptual understanding according to the achievement levels of pre-service teachers in their previously taken geometrical optics course.

In general, females were found to be less confident than males in science, and this confidence gap between males and females has been observed to widen as people get older [34–36]. However, lack of confidence does not necessarily indicate low ability. Even when females achieve as well as or better than their male counterparts, they tend to underestimate themselves. Gender differences in confidence are said to be dependent on context and on the domain being tested [35,58]. In their study, Jones and Jones [62] found that female students were less confident with science questions than male students. They also stated interactions in the ability level (high, low) and the type of question (science, math, familiar, unfamiliar), such that the high ability female students were found to be less confident than other groups (high and low ability males and low ability females) in science. In terms of gender differences in teachers' confidence in geometrical optics, no study has been met so far. Hence, the results of the present study contribute to the literature in its investigation.

The result of this study has several important implications. One of the implications is that teacher education programs need to conceptually teach physics. Pre-service teachers must have a solid conceptual understanding of basic concepts, such as light and optics in physics, because of their influence as future teachers on many students. For this reason, teacher preparation at the conceptual level is essential to ensure student learning. In order to improve the scientific preparation of teachers in geometrical optics, in addition to having strong pedagogical content knowledge on how to teach this particular subject more effectively, teachers need to have a better level of content knowledge in geometrical optics. Including specific advanced physics courses in teacher education programs would be desirable but insufficient. A more critical effort would be incorporating practical experiences and teaching courses with mostly conceptual content into pre-service teacher education programs. In redesigning the content of the courses for conceptual understanding in teacher preparation programs, special attention should be given to the topics beneficial for both sexes to reduce gender differences. The choice of content and contexts in which optics learning is embedded must be carefully considered. The results of previous studies [63–65], at several grade levels using different approaches in optics teaching and were empirically found to be superior to traditional teaching, should also be revisited for teacher education programs.

Another implication is that teachers' confidence in their conceptual knowledge should be increased. Considerable evidence suggests that many pre-service teachers do not understand their subject in depth. This weakness in content knowledge can undermine the confidence of the teachers [66]. An increase in competence is expected to accompany an increase in confidence. Hazari, Tai, and Sadler [39] stated that success in physics also influences attitudes; if females are well prepared, feel confident, and do well in introductory physics, they may be inclined to study physics further. However, as shown in the present research, even after several years of instruction and experience, the disparity in confidence between male and female pre-service teachers in geometrical optics is striking. Hoffman [48] acknowledged that giving girls a better opportunity in physics means supporting them in fostering a positive physics-related self-concept, which is one requirement for fostering

general interest in physics as well as for higher physics achievement. Jarrett [66] also stated that interest and confidence are related. According to their study, confidence is not solely dependent on the number of science courses taken in teacher preparation colleges, but also on the quality of the courses that model the way teachers are encouraged to teach science. Single-sex classrooms were reported to be one way of addressing girls' lower participation, interaction, and confidence in physics. Girls in single-sex classrooms claimed a greater sense of belonging, integration, and confidence in physics courses than their peers in mixed classrooms [58,67]. Nevertheless, thorough experimental studies investigating the effectiveness of single-sex classrooms compared to mixed ones for closing the gender gap are still needed.

The results discussed here are limited to the participants and the context within which this research was conducted. For future research, the next step might be a more in-depth investigation of why gender differences exist in conceptual understanding and confidence in a qualitative manner. Future research can also focus on finding effective ways to close the gender gap through experimental studies. The Cronbach's alpha coefficient stated in this study for the first tier of the FTGOT would be criticized. As stated before, with its strong distractors as a conceptual test, the FTGOT includes rather difficult items that reduce reliability coefficients. Thus, for future studies, the replication of the study by using a different test including conceptual questions in geometrical optics would be recommended.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board of Kocaeli University (protocol code 2015/039 and date of approval: 15 January 2015).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The Four-Tier Geometrical Optics Test (FTGOT) items can be downloaded at <https://physport.org/assessments/assessment.cfm?I=90&A=FTGOT>.

Conflicts of Interest: The author declares no conflict of interest.

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