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RESEARCH ARTICLE

THE DISPERSION OF WHITE LIGHT IN FINAL YEAR SCIENCE CLASS: STUDENTS' DIFFICULTIES AND PROPOSALS FOR TEACHING AND LEARNING

***Ahodegnon Zéphyrin Magloire DOGNON**

Institute of Mathematics and Physical Sciences, University of Abomey-Calavi, Abomey-Calavi, Benin

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***Corresponding author:**
Ahodegnon Zéphyrin Magloire DOGNON

ABSTRACT

This research studied the problems associated with the teaching and learning of white light scattering. It involved designing a paper-and-pencil questionnaire submitted to 102 pupils in the science final year of secondary school from ten general-education colleges in Benin to explore the types of difficulties they experience in learning about the dispersion of white light. Analysis of the students' responses revealed that they had serious difficulties in acquiring factual knowledge about the dispersion of light by a prism and in interpreting this phenomenon to explain common atmospheric phenomena. With this in mind, we proposed an innovative didactic approach to facilitate the teaching/learning of white light scattering in these science final year classes.

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INTRODUCTION

In this research, we study the learning difficulties of students in relation to the dispersion of white light in the final year of science. The aim is to propose a modular approach to developing the scientific and technical skills involved in alleviating the problems associated with teaching and learning geometrical optics. We present the institutional and theoretical framework of the research, then develop the methodology adopted and finally present the results.

The theoretical and institutional framework of the research: This study falls within the framework of research carried out in teaching and learning science on the construction of concepts in optics, and seeks to explore the difficulties Beninese students in science final classes have in understanding light dispersion. It is in line with Vygotski's theory of learning (Brossard, 2004), which states that learning precedes the development of the individual. The general guidelines for Benin's curricula stipulate that teaching and learning in Physics, Chemistry and Technology (PCT) must ensure that pupils develop a scientific approach in general and an experimental approach in particular. They base PCT on pedagogical and didactic considerations, among others. The pedagogical foundations are taken to mean that the guidelines give priority to curricula based on the competences approach based on constructivism and socioconstructivism. In final year class C and D, in addition to the general guidelines, the Physics Chemistry and Technology syllabus prescribes, on the one hand, the competences specified on a disciplinary, cross-disciplinary and cross-curricular basis and, on the other hand, a repertoire of themes and the knowledge and techniques associated with each learning situation, as well as the plan for its development. The study of the dispersion of white light, in the syllabus for the Terminale C/D class, corresponds to Learning Situation (L.S.) 5. The syllabus prescribes the implementation of the dispersion of white light by a prism and the implementation of the dispersion of light by a grating. (GPE Tle D, 2011, p.16). The teaching recommendations specify that the main concepts to be defined are the notion of light dispersion and the notion of the light spectrum. With regard to the dispersion of white light by means of a prism, the guide indicates:

> *[Emphasise] the quantitative aspect, i.e. the calculation of the angle of deflection of a light ray. In addition, the direction and extent of the deflection will be interpreted as a function of the wavelength of the radiation and it will be assumed that the refractive index n of the prism glass is a function of the radiation. This will be used to explain the rainbow phenomenon.* (GPE Tle D, 2011, p. 84).

From this extract, it is very clear that teachers are being asked to develop the concepts of light dispersion and light spectra by relying on procedural knowledge (procedures for calculating the deviation of incident light beams) to the detriment of qualitative considerations of the phenomena involved. According to the syllabus and guide of the study programme for the C and D final year classes on the dispersion of white light, the knowledges to be taught are:

- Recognition of the prism and the grating and how they are used to disperse light.
- Define the refractive index of a medium and remember that it depends on the wavelength of the light passing through it.
- Draw a spectrum of white light to see that it is made up of an infinite number of monochromatic radiations (Newton's experiments).
- Determination of the limiting wavelengths of the visible spectrum: 0.4mu and 0.8µm.
- Explanation of the rainbow phenomenon.

Skills targeted by the study of the dispersion of white light by a prism in Terminale C and D Two subject-specific skills targeted by the study of the dispersion of white light in Terminale Scientifique in Benin:

Disciplinary skill no. 1, which reads as follows:

″Develop an explanation of a fact or phenomenon in the natural or built environment, using modes of reasoning specific to the physical and chemical sciences and technology″. (PE, Tle D, 2011, p.54). The aim is therefore to help students understand how white light is dispersed by a prism or grating, and in particular the phenomenon of the rainbow, by using documentary analysis to take a quantitative approach to calculating the angle at which rays are deviated, in order to interpret the direction and extent of their deviation as a function of the wavelength of the radiation.

Disciplinary skill no. 2, which reads as follows:

"Use the physical and chemical sciences and the technological approach in the production, use and repair of technological objects". (PE Tle D, 2011, p.55)

At the end of the course, therefore, students should be able to propose, independently, an explanation of the phenomenon of the dispersion of white light by making and using a prism or grating.In view of the knowledge to be taught and the activities recommended in the syllabus, we can deduce the knowledge required in terms of theoretical and practical know-how.

Theoretical know-how

The theoretical skills required here essentially refer to the factual knowledge that students need to understand the dispersion of white light. For the student, this involves

- Defining the key concepts relating to light dispersion
- Grasp the rule for the passage of a ray of light from one refractive medium to another
- State Descartes' laws for the refraction of light
- Distinguish the main colors of the rainbow
- List of objects that decompose white light.

Practical know-how

The practical skills relating to the dispersion of light relate to

- Procedures for tracing the path of a ray of monochromatic light striking the prism at a given incidence;
- Establishing the laws of refraction for the two refractions undergone by the light through the prism;
- Determine the angle of the prism;
- Interpret the phenomenon of light dispersion.

PROBLEM, QUESTION AND HYPOTHESIS RESEARCH: The study of geometric optics is an integral part of teaching and learning at secondary level in Benin. (PE 6ème, 2020 ; PE 3ème, 2020 ; PE, T^{le}D, 2011). It continues all the way to university.In the final year science class, the study of the dispersion of white light takes place in SA n°5 and is crucial to understanding the phenomena of refraction, interpreting the decomposition of polychromatic light radiation such as white light and explaining the atmospheric phenomenon of the rainbow. Learning about the dispersion of light is essential for breaking down the epistemological/cultural and societal barriers that have led people to regard the rainbow as a divinity holding infinite treasure. Research into science education has focused on the dispersion of white light.In a very recent study, Pelissier (2023) set up an experimental device for studying the refraction of light at lycée, making it very easy to obtain measurements to establish the Snell-Descartes laws by means of demonstration (Johsua, 1989). As a result, students quite naturally confuse the light traces observed with the rays of light traced on the representation. This is an epistemological problem that is invisible to all the teachers and students interviewed.It is a form of distancing from the scientific practice of reference that Tiberghien (1994) has highlighted by inviting pupils to learn to distinguish between what comes under observations (direct or instrumented) and what comes under the representation of what we understand of the phenomena (model). To deal with this problem, Pelissier (Ibid, p.2) proposes, on the one hand, an older and more relevant experimental set-up and, on the other hand, a set-up inspired by Ptolemy's work on refraction reported by Viennot (1996). It is clear that the study of the dispersion of light is of educational interest.All these different observations lead to an interest in the difficulties of learning about the dispersion of white light in the final year of science.

This study, which focuses on theoretical knowledge and practical know-how, will help to improve the training of physics teachers in the types of activities to be offered to pupils so that they can make the most of them to learn about the dispersion of white light. Achieving our objective leads us to ask the following question: What difficulties do students in the final year science classes have with light scattering? The aim of this question is, on the one hand, to highlight the shortcomings of students in science final year classes in terms of learning the theoretical and practical knowledge of the dispersion of white light. On the other hand, the question is to explore the possible links between the two types of knowledge that would prevent them from appropriating the decomposition of white light. In view of the way in which the study of light scattering is implemented, which is not very respectful of the approach to the study of the subject, and in view of the pedagogical and material organization of the secondary schools in question, we postulate that pupils have difficulty in assimilating theoretical and practical knowledge of the phenomenon of white light scattering, and that this is dependent on the mutual influence of the inadequacies of the two types of knowledge.

METHODOLOGY

Le recueil des données : The physical setting for our study was ten secondary schools, including three in the Plateau department: CEG Tatonnonkon, CEG Ikpinlè, CEG Ifangni, and seven in the Ouémé department: CEG Dowa, lycée Béhanzin, CEG Davié, CEG Adjohoun, CEG Dangbo, collège privésainte CENIA and collège Notre Dame de Lourdes de Dowa.The panel we set up comprised 102 students in the final year of the C and D series who had already taken the course on the dispersion of white light. Our aim in this study was to explore the difficulties experienced by students in the science final year in understanding the dispersion of white light. To this end, the paper-and-pencil questionnaire was the most appropriate technique for collecting data. We submitted a paper-and-pencil questionnaire to the 105 students on our panel, based on questions relating to the two types of knowledge about light scattering:

- Questions relating to theoretical knowledge
- Questions relating to practical know-how

Questionnaire on theoretical knowledge: Students were asked questions relating to declarative knowledge on the subject of light dispersion. These included the definitions of monochromatic light and polychromatic light, the refraction of light, the refractive index of a medium, the prism and the definition of light dispersion (SFT 1). Students were also asked to specify the rule for the passage of a light ray from one refractive medium to another (SFT2), to state Descartes' laws for the refraction of light (SFT3), to list the different colors of the rainbow (SFT4) and to indicate some objects that decompose white light (SFT 5).

Questionnaire on practical know-how: Interpretation of the phenomenon of light scattering. The students were given a series of four questions to help them interpret the phenomenon of white light dispersion. The first question consisted in tracing the path of a ray of monochromatic light striking a prism at an incidence i (SFP1). The construction used Snell-Descartes' law of refraction. The ray of incidence i undergoes two successive refractions (1st refraction r and 2nd refraction r') before emerging from the prism two successive refractions at an angle of incidence i'. The construction is an application of Snell-Descartes' law of refraction. The incident ray i undergoes two successive refractions (1st refraction r and 2nd refraction r') before emerging from the prism with two successive refractions at an angle of incidence i'. Relationships $n_{air} sini = nsinr$with$n_{air} = 1$and the refractive index of the prism glass having been given, as well as the value of i, the students should easily draw the path of a ray through the prism as follows. In a second question, the students were asked to establish the laws of refraction for the two refractions undergone by the light through the prism (SFP2.a) and to determine the angle D of deviation between the emergent ray and the incident ray as a function of the angle Â of the prism, the angle of incidence i of the prism and the angle r' of the 2nd refraction (SFP2.b). In a third question, students were given a figure illustrating the decomposition of a beam of white light by a prism (see Figure 1 reproduced below) and asked to name and interpret the phenomenon illustrated (SFP3). Finally, the students were asked to propose an explanation for the rainbow phenomenon (SFP 4).

Data processing and analysis

The following steps were taken to extract the data from the questionnaires completed by the pupils:

- Firstly, we designed the grid for correcting the work produced by the pupils surveyed, preparing the expected answer for each question. We then chose to assign the number 1 to each answer that was consistent with the expected answer and the number 0 to each answer that was not consistent with the expected answer.
- Secondly, we compiled a table for each student showing their score for each variant of the type of knowledge assessed (theoretical or practical knowledge).

The advantage of this way of weighting the results lies in the fact that all the averages we calculate are the success rates for the knowledge assessed, or the percentages of students who passed a given question relating to a given type of knowledge about the dispersion of white light. Once the data have been extracted in this way, we process them using Microsoft Excel software, calculating the average success rate for each student for each variant of a type of knowledge. Finally, we generated the corresponding graphs in order to carry out the necessary qualitative analyses. In the following table (Table 1), we record the different codes we adopted for the different variables.

Table 1. Coding of the knowledge variants assessed

Variants of Theoretical Know-How (TK)					Variants of Theoretical Know-How (TK)
SFT1	SFT2	SFT3	SFT4	SFT5	
Question 1	Question 2	Question 3	Question 4	Question 5	
Variants of Practical Know-How (PKS)					
SFP1	SFP2	SFP3	SFP4		
Question 6	Question 7	Question 8	Question 9		

THE RESULTS OF THE RESEARCH

Table 2 shows the results of the analysis of the students' productions for theoretical and practical know-how and their variants.

Table 2. Compilation of the results of the analysis of students' work

	Theoretical know-how (SFT)						Practical know-how (SFP)				
Know-how	**ST1**	**ST2**	**ST3**	**ST4**	**ST5**	**%SFT**	**SP1**	**SP2**	**SP3**	**SP4**	**%SP**
% success	**25,49**	**24,51**	**61,76**	**63,73**	52,94	45,69	**47,06**	**50,98**	**3,92**	**2,94**	**26,23**

In this table we record for each student the result of his or her production for each type of knowledge and for each of its variants, and we calculate the success rate for the theoretical type of knowledge and for the practical type of knowledge (last column for each type of knowledge). We also calculate, for all 102 students in our panel, the average success rate for each variant of each type of knowledge.

Analysis and interpretation of the data collected on students' theoretical knowledge about the dispersion of white light: From Table 2 we obtain the graph in Figure 1 below, which shows the results of the students' productions with regard to theoretical skills.

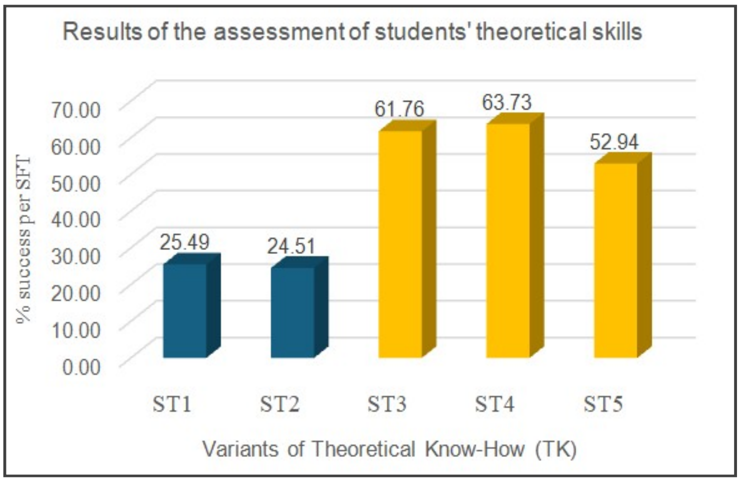

Figure 1. Results of the assessment of students' theoretical knowledge of the dispersion of white light

Examination of this graph shows that barely a quarter of the pupils questioned could define monochromatic and polychromatic light, the refraction of light, the refractive index of a medium, a prism and the dispersion of light (ST1: 25.5%). The same applied to the rule for the passage of a ray of light from one refractive medium to another (ST2: 24.5%). Just over six out of ten students were able to correctly state Descartes' laws for the refraction of light (ST3: 61.8%) and list the main colours of the rainbow (ST4: 63.7%). Finally, the results show that just over half of the students questioned (52.91%) were able to cite examples of objects that decompose white light. So the majority of the students in our panel don't seem to be able to grasp the basic concepts of light dispersion, even though they can state Descartes' laws of light refraction. Calculation of the average overall success rate for theoretical know-how (47.7%) shows a low success rate for questions relating to theoretical know-how on the part of pupils concerning the dispersion of light. Thus, the exploration of the theoretical knowledge relating to the dispersion of white light among the pupils of the ten schools enabled us to highlight a lack of mastery of definitional knowledge.

Analysis and interpretation of the data collected on students' pratical knowledge about the dispersion of white light: A graph was also generated showing the results of the students' work on the practical skills relating to the dispersion of white light (Figure 2).

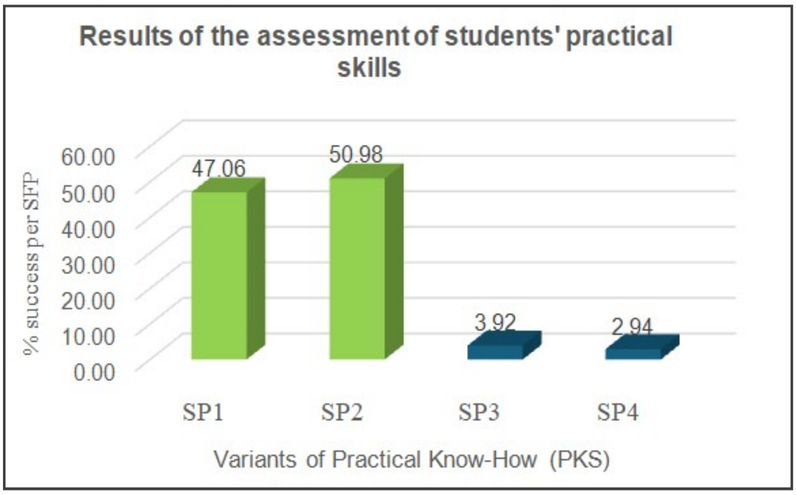

Figure 2. Results of the assessment of students' theoretical knowledge of the dispersion of white light

The graph shows that barely half the students questioned (47.06%) were able to use Descartes' laws of light refraction to trace the path of a ray of monochromatic light striking a prism at an angle of incidence i (ST1). Similarly, half of them (50.98%) succeeded in establishing the laws of refraction for the two successive refractions undergone by the light through the prism and managed to determine the angle D of deviation between the emerging ray and the incident ray as a function of the angle Â of the prism, the angle of incidence i of the prism and the angle r' of the 2nd refraction (SP2).

The observations show that barely 4 out of 100 students questioned (SP4: 03.92%) were able to explain the phenomenon of white light dispersion and barely 3 out of 100 were able to infer an explanation for the rainbow phenomenon. One might expect that half the pupils who succeeded in applying Descartes' laws of refraction to construct the path of a light ray through a prism (SP 1) and in establishing the relationship enabling them to predict the total angle of deviation of the ray as it exits the prism (ST 2) would manage, in the same proportions, to explain the phenomenon of light dispersion and to infer one for the rainbow phenomenon. The results showed a different situation, suggesting that there was no link between the acquisition of procedural skills (SP 1 and SP2) and strategic skills (complex), and that it was very difficult to explain physical phenomena. We calculated the overall average pass rate for practical skills (SFP) and obtained 26.23% (see Table 3). As with practical skills, this shows a very low success rate for questions relating to students' practical skills.

The results of the study: Our study consisted in answering the following question: "What difficulties do pupils in sixth form classes have with the phenomenon of the dispersion of white light? Our analyses enabled us to identify profound difficulties in pupils' understanding of light dispersion in several respects: Problems in acquiring theoretical knowledge We identified problems in pupils' acquisition of theoretical knowledge.

These concern:

- Difficulties in correctly defining the basic concepts of light dispersion (monochromatic and polychromatic light, refraction of light, refractive index of a medium, the notion of prism and light dispersion).
- Difficulties in stating the rule for the passage of a light ray from one more or less refractive medium to another. Problems in acquiring practical skills.

The study revealed that the pupils had difficulties in :

- Interpreting the phenomenon of refraction
- Their ability to explain the rainbow phenomenon on the basis of Descartes' laws of refraction.

PROPOSAL TO DEVELOP THE TEACHING OF WHITE LIGHT SCATTERING

The need for a modular approach to the study of white light dispersion. The analysis of the prescribed curriculum carried out above made it possible to identify the theoretical know-how and practical skills required for the proper implementation of the phenomenon of light scattering. Analysis of the pupils' work revealed conceptual shortcomings in terms of both factual knowledge and interpretation of the phenomenon of light scattering. This is why, with a view to training, we are proposing the development of a form that can be used to design a teaching document to optimize the management of learning about light scattering. Presentation of the scientific and technological skills sheet on light scattering. On the basis that a competency is a power to act, to succeed and to progress that enables tasks or activities to be carried out appropriately and that is based on an integrated set of knowledge, skills, attitudes and behaviors, we propose to reconfigure the subject-specific competency in question into a scientific/technological competency related to light scattering: "Applying the principles of light scattering".We have defined the "context of performance" of scientific and technological competence. The context of performance corresponds to the terms and circumstances that have a decisive impact on the performance of the task and illustrate, in particular, the work environment, the occupational health and safety risks, the equipment, materials and reference works used to perform the task. More specifically, it covers the regulatory framework, the workplace, the degree of collaboration, the degree of supervision, specific instructions or initial data, references used, tools, equipment, health and safety hazards, etc. The scientific and/or technological competency is broken down into "competency elements", which describe the competency in terms of specific behaviours. They are limited to the data needed to understand the scientific and technological skill. They can be defined in two different ways: they specify the main stages in the implementation of the competency or they describe its main products or results. Each element represents a stage that is a significant key moment in the competency.Two competency elements are retained for the "Apply the principles of light dispersion" competency: (1) *Describe the basic principles of light refraction*, (2) *Exploit the fundamental principles of light dispersion*. "*Specific performance criteria*" are associated with each competency element. They define the requirements to be met and provide details of the expected behaviour. They also enable a rigorous assessment to be made of whether the competency has been achieved via the competency element, with a view to evaluating the competency. Detailed presentation of the development sheet for the teaching of light scattering in the science final year of secondary school.

Table 3. Development of the "Apply the fundamental principles of white light dispersion" competency

DISPERSION OF WHITE LIGHT	
Scientific and technological competency statement	**Context of performance**
Apply the principles of light dispersion	• Individually or in a group **from**: • written or verbal instructions • documentation on light scattering • various situations involving the phenomenon of light scattering • **With the help of**: • relevant documentation • optical bench • prism • laser source • technical files • audiovisual equipment • computers • safety equipment • protocols, databases and references concerning the refraction of light • technical and scientific documents relating to the refraction of light • technical data sheets and leafletswebsites
Elements of scientific and technological competence	**Specific performance criteria**
1. Describe the basic principles of light refraction	• Correct definition of monochromatic light; • Correct definition of polychromatic light • Correct definition of the refraction of light; • Correct definition of the refractive index of a medium • Correct description of a prism

	• Correct definition of light dispersion • Correct statement of the rule for the passage of a light ray from one more or less refractive medium to another • Correct statement of the Snell-Descartes laws for the refraction of light • List all the main colors of the rainbow: • Correctly distinguish common objects capable of decomposing light
2. Exploit the fundamental principles of light dispersion	• Correct interpretation of the Snell-Descartes laws • Correctly trace the path of a monochromatic light ray as it intercepts a prism • Rigorous establishment of the laws of refraction for the two refractions undergone by the light through the prism • Rigorous determination of the expression for the prism angle • Accurate calculation of the angle of deflection of a ray after passing through a prism • Accurately set up an experiment on the dispersion of a beam of white light by a prism • Precise interpretation of the dispersion of light by a prism • Judicious implementation of the dispersion of sunlight by a prism • Correct application of the dispersion of sunlight by common objects (grating, bird feather, compact disc, air bubble in soapy water) • Correct interpretation of the rainbow phenomenon

Developed in this way, this module sheet is the prescribed basic tool for developing teaching aids such as learning manuals and training guides for teaching and learning about light scattering.

CONCLUSION

This article explores the problems encountered by students in learning to disperse white light in the final year of science. The learning difficulties highlighted by this study, in addition to the epistemological problems involved, should serve to enrich the training materials for teachers responsible for implementing light scattering. The proposed modular approach to the development of scientific and technological skills will help to rethink training curricula in physics, chemistry and technology.

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