Semiotic Registers Recognition on Mechanical Energy in High School Students: Questionnaires Validation

Energy apprenticeship in High School Students: Questionnaires validation

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***Abstract*— This study is part of a broader research initiative focused on the effective use of semiotic registers in the teaching and learning of mechanical energy among high school students. The research is grounded in a theoretical framework that addresses the learning of mechanical energy from a comprehensive perspective, incorporating various semiotic tools such as diagrams and mathematical models. Duval's Theory of Semiotic Representation Registers (TRRS) is examined as an alternative approach to designing educational strategies in physics. This paper presents the validation process of two questionnaires: C1, which assesses students' levels of recognition of semiotic registers related to work and energy, and C2, which evaluates their understanding of mechanical work. The findings indicate that the instruments possess strong content and internal validity, making them suitable for use in subsequent data analysis during the research process.**

***Index Terms*— Mechanical Energy, Semiotic Registers, Validation**

***Resumen*—Este documento hace parte de los resultados de investigación sobre el uso consciente de los registros semióticos en el aprendizaje de la energía mecánica en estudiantes de la escuela media. Por lo tanto, se parte de un desarrollo teórico donde se enmarca el aprendizaje de le energía mecánica desde una perspectiva amplia y que se sustenta en el uso de distintas herramientas semióticas tales como los diagramas y modelos matemáticos. Luego se analizan las posibilidades que brinda la teoría de los registros de representación semiótica de Duval (TRRS) como una alternativa para configurar propuestas de aprendizaje en física. Desde este trabajo se presenta el proceso de validación de dos cuestionarios C1 para evaluar los niveles de reconocimiento de registros semióticos sobre trabajo y energía y C2 para examinar los niveles de comprensión sobre trabajo mecánico. Según los resultados, los instrumentos que se presentan tienen validez de contenido e interna para que se utilicen en el proceso de análisis de los datos en la investigación correspondiente.**

***Palabras claves*— Energía Mecánica, Registros Semióticos, Validación**

I. INTRODUCTION

This document is part of a doctoral thesis in didactics of natural and exact sciences that seeks to understand the interactions between learning mechanical energy in High School students (15 to 16 years old) and the conscious use they make of the different semiotic registers to achieve the construction of knowledge..

To begin with, it must be understood that learning problems in students have multiple causes. Among these, the negative attitude that a large part of the students has towards learning science and especially physics and chemistry [1], [2] stands out. Therefore, it is necessary for science education to work in dimensional and multidimensional perspectives to analyze epistemological and historical aspects of the contents, the cultural, cognitive, emotional aspects of the students and also the interactions in the classroom [3], [4].

Among the causes of disinterest, the status of science, religious and cultural influences are mentioned because some consider that science contributes to well-being, but others believe the opposite, especially due to warlike conflicts and the use of state-of-the-art weapons. technology.

On the other hand, some researchers argue that this problem arises from the weaknesses that occur in the mathematics training processes and the relationships between this science and physics.

In relation to the learning processes of mechanical energy, [5] states that weaknesses are observed in the learning processes in first-year university students. Among these, the following stand out: difficulties in explicitly defining a system, using forces in a vectorial manner, applying Newton's third law and the concept of work and, in addition, in justifying and arguing. Numerous semiotic representations are used in these processes.

In addition, in many didactic processes, little conscious and structured use is made of these without considering, for example, that the iconic representations similar to the concrete world that were previously used from geometry, today are made with graphic representations that are associated with models. abstract mathematics [6] and also, with an increase in ICT [7].

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At the same time, [8] states that the multiple roles that the same representation can play within an analysis should be considered when an arrow, for example, is used to indicate or point, but also to show force, speed and acceleration. These are used in schematics and diagrams when phenomena are analyzed from the perspective of representations.

In this way, the objective of this document is to show the validation process that is followed for two questionnaires in the learning process of mechanical energy.

THEORICAL PERSPECTIVE

A. The Notion of Energy in Physics.

La The understanding of the concept of energy in the context of physics is complex due to several aspects. Among these, the following stand out: 1- firstly, from the point of view of history, this concept is associated with the notions of "push and pull" that influence the didactic processes [9], 2- secondly, its etymological origin comes from the common language that the English associate with the production of mechanical work during the industrial revolution [10], [11], [12], 3- thirdly, the construction of some central concepts such as kinetic energy arise from the different views to try to quantify the amount of movement of a body. These were Newton's on momentum and momentum (m.v) and Leibniz's called Vis Viva ($m.v^2$) [13], 4- fourthly, the study of didactic processes from alternative or erroneous conceptions involves implicit aspects of the internal representations of the students but it is complex to relate them to the established mathematical models [14], and 5- fifthly, to understand energy from physics, other complex ideas such as the notion of system must be developed [15].

B. The system idea in order to understand the energy from mathematics.

The understanding of energy from the notion of systems is made from mathematical models that consider that there are three types of energy in a system: kinetic, potential, and internal. Likewise, they take heat, mechanical work, radiation, waves, matter, and electricity as mechanisms of energy transfer and not forms of energy. Therefore, motion, height, strain, temperature, and pressure are taken as sources for the types of energy that are mentioned [15], [16], [17], [18], and [19].

Therefore, some researchers suggest that the study of energy be done from a unifying (PU) and broad (PA) perspective.

In relation to the PU, these contemplate addressing the issue of energy from the different themes of physics. For example, from classical physics one can mention mechanics, fluids, thermodynamics, etc.

Respecting the PA, it is proposed to study energy within a theme considering: energy sources, types, transformation processes, transfer, conservation, and degradation of energy.

C. The semiotic tools in PA.

Some semiotic tools such as bar charts, energy, and flow tracking, have an intuitive and metaphorical nature [20] and are used in energy learning processes, researchers such as [9] cite Strike and Posher, Hammer and they argue that they can generate errors in the learning processes; they also constitute valuable alternatives for the broad understanding of energy that should be investigated to determine their effectiveness.

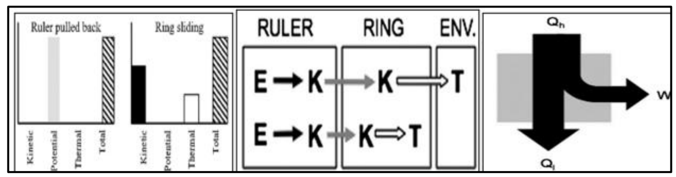

Fig. 1. Energy Tracking Diagram for a hand compressing a spring at constant speed. C, K, T, and E represent chemical, kinetic, thermal, and elastic energy, respectively. White, gray, black, striped, and hatched arrows represent metabolism, thermal conduction, elastic compression, mechanical work, and dissipation, respectively. Obtained from [21] y [22].

Some authors, such as [23], analyze certain problems that arise when a semiotic representation is used to illustrate the interaction between two systems.

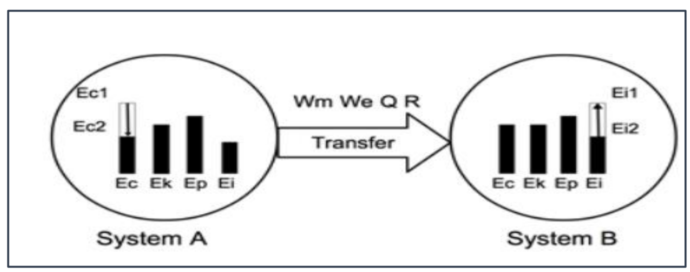

Fig. 2. Taken from [23], C: Chemistry, K: Kinetic, P: Potential, i: Intern, m: mechanic, e: electrical, Q: Heat; R: Radiation.

The problem emerges when the two systems are represented in the classroom, but the transfer processes are omitted, erroneously assuming that the students know them [24].

Multiple and multimodal representations are also semiotic tools that allow the learning of mechanical energy.

Regarding the use of multiple representations, [25] this one shows the relationships between the use of pictorial, graphic, numerical, and linguistic elements in the analysis of mechanical energy.

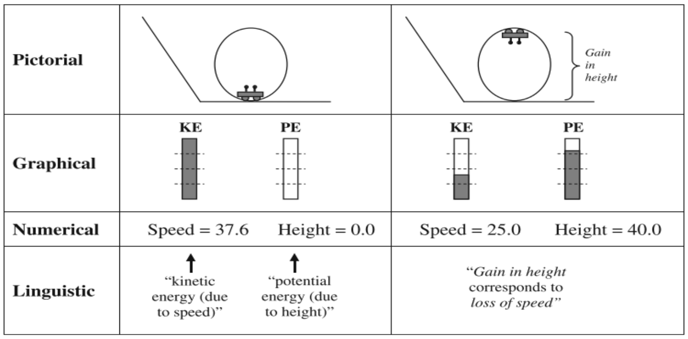

Fig. 3. Using multiple representations to analyze mechanical energy. Taken from [25].

Also, [25] illustrates the use of multimodal representations where gestures constitute representations used by teachers to try to explain concepts supported by explanations and arguments.

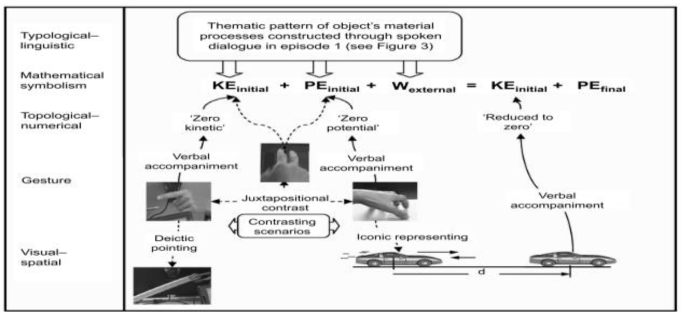

Fig. 4. Multimodal representations in the classroom. Taken from [25].

Finally, [26] shows the use of energy blocks as an alternative to relate concrete and abstract aspects in the representation of elastic potential energy in a spring.

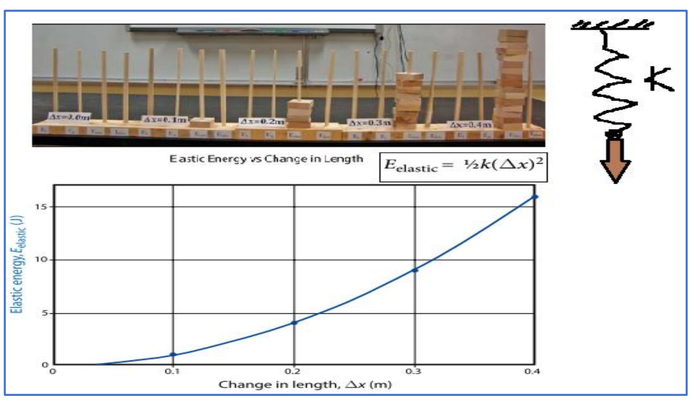

Fig. 5. Energy blocks diagram. Taken from [26].

D. The Theory of Semiotic Representation Records for Physics (TRRS).

In Duval's TRRS, a semiotic record is a type of representation that allows three operations: 1- it has conformity rules that allow its recognition within a theoretical context (Formation), 2- it can be transformed into another type of representation without changing the elements denoted (conversion) and furthermore, 3- it has some rules for its transformation within the same record (treatment) [27], [28].

According to the possibilities of converting one register into another, it is said that there is a greater or lesser degree of congruence between them.

This theory has as its theoretical bases the inferentialist perspectives of the sign and the triadic semiotic models where an attempt is made to understand the construction of knowledge from the interaction of both external (semiotic) and internal (thought) representations.

Although the TRRS was born for the field of mathematics, its application in physics is possible when the characteristics of the topics studied are taken into account. For example, [29] shows some applications of semiotic registers in physics where continuity problems in the use of some semiotic registers are highlighted.

For example, when analyzing uniform rectilinear motion, it works with continuous mathematical functions that allow greater degrees of congruence than when working with the topic of energy.

An investigation on the implementation of Duval's TRRS in physics is illustrated in [30], and confirms that the main shortcomings that students present in solving problems in physics are in the conversion. For this, he proposes a segmentation in significant elements of the problem to try to increase the levels of congruence of the records and understanding in the students.

A proposal to implement the TRRS in the classroom is made with the investigations of [31], [32] and [33] where the triadic semiotic registers (RST) are configured from their referential components with iconic and verbal registers; a vehicular component that is constituted with algebraic, graphic and symbolic registers and also, a component of meaning from verbal registers that are expressed with natural language.

II. OBJECTIVE

Analyze the validation process that is followed in two questionnaires for the learning of mechanical energy in High School students (15 to 16 years old): 1-The first is related to the levels of recognition of semiotic registers on work and energy C1, 2- While the second analyzes the learning of mechanical work C2.

III. METODOLOGY

The validation process contemplates two questionnaires C1 and C2. The C1 is a questionnaire on semiotic registers on work and energy for average students. In relation to C2, it is a questionnaire that seeks to analyze the levels of understanding that students have about the vectorial application of mechanical work in real situations. The collection of information is done through Google forms or in person. It has the participation of 10 secondary school teachers and 3 international research experts. The information is collected between the months of June and August 2022.

Next, the structure of C1 is illustrated, which begins with 19 questions and after conducting the first focus group is reduced to 7.

TABLE I.
COMPONENTS OF THE QUESTIONNAIRE ON RECOGNITION OF SEMIOTICS RECORDS (C1)

Questions	Subjects	Types of registers		
		Referential	Vehicular	Sense
P1	Force, work, energy, power	I (1): Schemes	S (5): Variables	V (5): Name of the variables
P2	Free body diagram (Forces): displacement, applied force, weight, normal		G (1): Free body diagram	V (5)
P3	Mechanical work	I (1): Schemes	G (orthogonal coordinate), A (2): Equations	V (4): keywords
P4	Types of mechanical energy (Kinetic, Potential) and mechanical work.	I (5): Schemes	A (5): Equations	V (5): Equations description
P5	Efficiency, power, and mechanical work.	I (3): Schemes	A (3): Equations	V (3): Equations description
P6	Mechanical energy	I (1): Photo	A (2): Equations	V (2): Equations description
P7	Measuring units for energy.		S (14): Measuring units	V (7): Measuring units description

Note: I (iconic registers), S (symbolic registers), V (verbal registers), A (algebraic registers), G (graphic registers): Type of registers (number of registers implicated)

The design for question 4 is shown below.

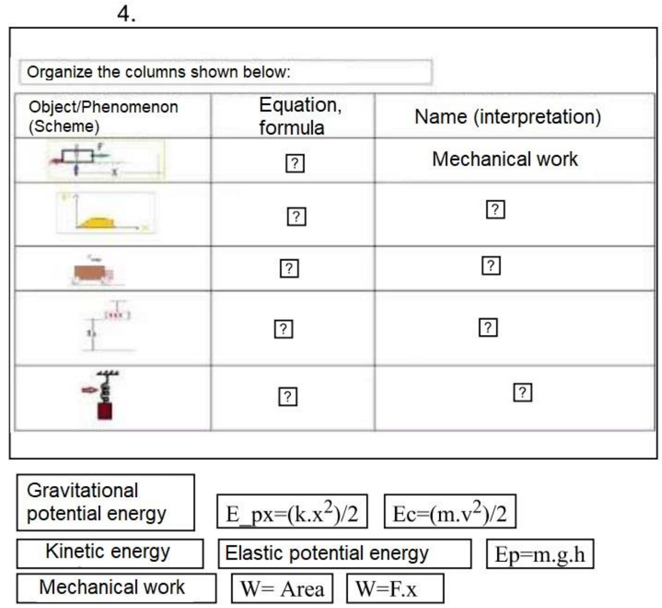

Fig. 6. Question # 4 of C1. Own design on the platform https://www.thatquiz.org/es.

There are three columns in the previous question. The first column has iconic records that serve as a reference for the related concept. From these, students must drag or write in each question the corresponding equation and description.

In relation to C2, a questionnaire with 8 situations is designed to analyze the levels of understanding about mechanical work applied by an external force to a body from the misconceptions in 4 levels as stated in [34].

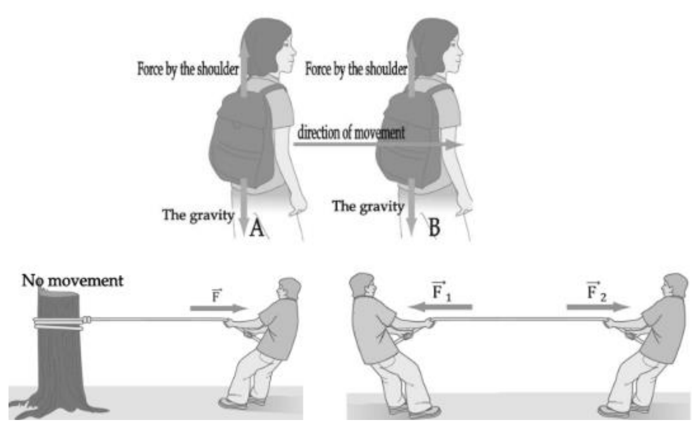

Fig. 7. Situations to analyze the vectorial application of mechanical work. Taken from [34].

In his research, [34] proposes to evaluate the application of the model and the level of security in the students' responses. According to the researcher, the student presents resistance to learning while choosing both incorrect answers and high levels of security against them.

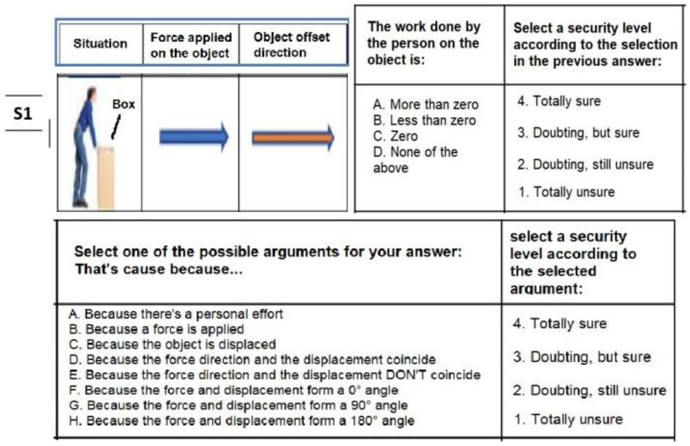

Fig. 8. Situations No 1 to analyze the vectorial application of mechanical work. Own.

Figure 7 shows a person dragging a box on a horizontal surface. The direction in which the force is applied, and the direction of the body's displacement are shown below. The student is then asked if the work done on the body is: greater than zero, less than zero, equal to zero, or none of the above. Then they are asked to select a level of security against the selected answer as follows: 1- Totally insecure, 2-insecure with some confidence, 3- sure with some doubts 4-totally sure.

The results of the analysis reveal for each situation the type of correct understanding C.C, partial C.P, alternative C.A or null C.N that the student has for each situation.

In relation to the C.C, it occurs when the student selects both the item and the correct argument with a security level equal to 3 or 4. The C.P occurs when the student selects the item or the correct argument, but with security levels of 1 or 2. The AC is the one of greatest interest to researchers because in it the students select both the item and the incorrect argument with security levels of 3 or 4. According to the researchers, in these cases there may be resistance to the processes of learning. Regarding the N.C., it occurs when both the incorrect items and arguments are selected with security levels of 1 or 2.

The 8 situations proposed in the C2 questionnaire are described below.

TABLE II.
C2 SITUATION CHARACTERISTICS

Situation	Description
S1	A box is dragged on a horizontal surface by a force in the same direction as the displacement
S2	A backpack is being carried in someone's back
S3	A box is lifted from the floor by a force applied in the direction of the body's displacement.
S4	A bag full of objects is carried by holding it in front of the chest
S5	A box is dragged on a horizontal surface by a force inclined towards the floor
S6	A load moves horizontally on the shovel or bucket of a backhoe.
S7	An elevator lifts three people.
S8	A person carries an object and climbs the stairs

A. Content and intern validation.

Results were analyzed for the 13 experts.

IV. RESULTS

A. *Results for C1*: Questionnaire on the recognition of semiotic registers of work and energy for High School students (15 to 16 years old).

The table of characteristics of the experts who participate in this process is shown below.

TABLE III
C1 EXPERTS CHARACTERISTICS

Experts	Expertise areas	Years of teaching experience	Country
E1	Physics, Mathematics	15	Colombia
E2	Physics, Mathematics	9	Colombia
E3	Other	3	Colombia
E4	Physics, Mathematics	30	Colombia
E5	Physics	7	Colombia
E6	Physics	24	Colombia
E7	Physics	30	Mexico
E8	Mathematics	30	Colombia
E9	Other	15	Colombia
E10	Mathematics	10	Colombia
E11	Physics, other	35	Colombia
E12	Physics	22	Brazil
E13	Physics	1	Indonesia

The following questions were made relating each statement in the table I of the questionnaire C1.

1.1. The question is easily understood (clear, precise, unambiguous, according to the level of information and language of the respondent).
1.2. The answer options are adequate.
1.3. The answer options are in the correct order.
1.4. It is pertinent to achieve the GENERAL OBJECTIVE of the investigation.
1.5. It is pertinent to achieve the SPECIFIC OBJECTIVE #1 of the investigation.
1.6. It is pertinent to achieve the SPECIFIC OBJECTIVE #2 of the research.
Observations.

The values taken for each item are:

1 = strongly disagree; 2 = disagree; 3 = disagree more than agree; 4 = agree more than disagree; 5 = agree; 6 = strongly agree)The objectives to which these items refer are the following:

Main Objective

Analyze the relationships between the conscious use of the RST on work and energy in the Mechanical Energy learning from one (P.A) in High School students (15 to 16 years).

Specific Objectives

1- Comprehensively characterize through the use of semiotic registers of work and energy in the initial understanding that students have of the average about mechanical energy.

2- Implement a didactic unit for the broad understanding of mechanical energy in High School students through the conscious use of the RST on work and energy.

3- Evaluate the interactions between the conscious use of the RST on work and energy and the broad understanding of mechanical energy in high school students due to the didactic unit that is implemented.

The internal validity of the instrument is analyzed with the pre-test and post-test application for a pilot sample of 8 students from the Cristo Rey Educational Institution of Dosquebradas-Risaralda Colombia. The pre-test is applied on March 30, 2022, while the post-test is carried out on July 27, 2022. The results are shown below.

Students	**Pre-test (%)**	**Post-test**							**Average**
		P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**Post-test (%)**
E1	67	1,0	1,0	1,0	1,0	0,3	1,0	0,5	83
E2	31	0,7	1,0	1,0	1,0	0,3	0,0	0,1	60
E3	46	0,6	0,4	1,0	0,9	0,3	1,0	0,0	60
E4	41	0,7	1,0	1,0	0,8	0,3	0,0	0,2	58
E5	59	0,7	1,0	1,0	1,0	0,3	1,0	0,1	73
E6	5	0,7	0,4	1,0	0,6	0,0	0,0	0,2	41
E7	62	0,8	1,0	1,0	1,0	0,3	1,0	0,4	78
E8	39	0,7	1,0	1,0	1,0	0,3	0,0	0,2	61

The internal validity index is calculated using Cronbach's Alpha coefficient according to the recommendations of [35] , where the range between 0.8 and 0.9 indicates that the instrument has good internal validity.

Cronbach's Alpha coefficient is calculated for the pretest and posttest values, finding a result of 0.94 (94%), which represents a high level of reliability.

B. Results for C2: Questionnaire on mechanical work for high school students (15 to 16 years old).

The list of participating experts is shown below.

TABLE IV
C2 EXPERTS CHARACTERISTICS

Experts	**Expertise areas**	**Years of teaching experience**	**Country**
E1	Physics, Mathematics	15	Colombia
E2	Physics, Mathematics	9	Colombia
E3	Physics	7	Colombia
E4	Other	3	Colombia
E5	Physics	24	Colombia
E6	Physics	30	Mexico
E7	Mathematics	10	Colombia
E8	Other	15	Colombia
E9	Other	30	Colombia
E10	Physics, Other	35	Colombia
E11	Mathematics	30	Colombia
E12	Physics	22	Brazil
E13	Physics	1	Indonesia

The content validity for C2 is carried out taking as reference the contributions of [36] and [37] on the Lawshe model (1975) modified by [38].

For calculating the coefficient of content validity according to the Lawshe model, each expert was asked if the item in question is considered "Essential", "Useful but not essential" and "Not essential". The equation with its parameters is shown below.

$CVR=\frac{n_e-\frac{N}{2}}{\frac{N}{2}}$ *Equation 1. Content validation index.*

n_e: number of experts qualifying the item as "Essencial"
$N: total\ number\ of\ experts$

$CVR' = \frac{CVR+1}{2}$ *Equation 2. Content Validity Ratio for each item (corrected CVR, this must be greater than 58%)*

$CVI = \frac{\sum_{i=1}^{M} CVR_i}{M}$ *Equation 3. Total Content Validity Index of the instrument.*

$CVR_i: Item\ with\ acceptable\ CVR$
$M: Total\ number\ of\ acceptable\ items$

The results of the data analysis are shown below.

TABLE V
CALCULATION OF THE CONTENT VALIDITY INDEX FOR C2

Experts	Situations							
	S1	S2	S3	S4	S5	S6	S7	S8
E1	C	B	A	A	A	A	A	B
E2	A	A	A	A	B	A	A	A
E3	A	B	A	C	A	A	B	A
E4	B	B	B	B	B	B	B	B
E5	A	B	A	A	A	B	A	A
E6	A	A	A	B	A	B	B	A
E7	A	A	A	A	A	A	A	A
E8	A	A	A	A	A	A	A	A
E9	A	A	A	A	A	A	A	A
E10	A	A	A	A	A	A	A	A
E11	A	B	A	B	A	A	A	A
E12	A	A	A	A	A	A	A	A
E13	B	A	A	B	A	A	A	A
Essential	**10**	**8**	**12**	**8**	**11**	**10**	**10**	**11**
CVR	**0,54**	**0,23**	**0,85**	**0,23**	**0,69**	**0,54**	**0,54**	**0,69**
CVR'	**0,77**	**0,62**	**0,92**	**0,62**	**0,85**	**0,77**	**0,77**	**0,85**
CVI	**0,77**							

Then, the validity of the instrument is analyzed by applying the questionnaire to 32 11th grade students of the Cristo Rey Educational Institution on August 22, 2022. To calculate the Cronbach's alpha coefficient, the values were changed as follows: C.C = 5; C.P =3; C.A = 2 and C.N = 1, obtaining a value of 0.82 (82%), which represents a high reliability index.

V. CONCLUSION

According to the results, the content and internal validity for C1 is 92% and 94% for a total average value of 93%. For C2, a content validity of 77% and internal validity of 82% are obtained for a total average validity of 79.8%. According to the results, the instruments are considered validated for their application in the information analysis process in the aforementioned research.

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