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# Design and validation of an instrument to evaluate the implementation of STEAM with a focus on inquiry for learning the Solar System on elementary school

# Diseño y validación de un instrumento para evaluar la implementación de STEAM con un enfoque en la indagación para el aprendizaje del Sistema Solar en educación primaria

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**Abstract**

The purpose of this article is to describe the steps for the design and validation of a measurement instrument. The importance of the analysis of the conceptual literature for the measurement of the variables, the calculation of validity through the Content Validity Coefficient through Validation by Expert Judgment and the calculation of the Reliability Coefficient of the instrument, through the Cronbach's alpha. As a methodology, the process for the construction of an instrument to measure psychoeducational variables was used, specifically explaining each of its seven phases. The results obtained indicate that the instrument has an excellent level of validity and agreement; as well as a very high level of reliability. It is concluded that there is a valid and reliable measurement instrument to measure the implementation of STEAM with a focus on inquiry for learning the solar system in primary education and that its application for which it was designed is suitable.

**Reliability, Validation, STEAM, Inquiry, Elementary School, Measuring instrument**

**Resumen**

El propósito de este artículo es describir los pasos para el diseño y validación de un instrumento de medición. Se resalta la importancia del análisis de la literatura conceptual para la medición de las variables, el cálculo de la validez a través del Coeficiente de Validez de Contenido mediante la Validación por Juicio de Expertos y el cálculo del Coeficiente de Confiabilidad del instrumento, a través del alfa de Cronbach. Como metodología se utilizó el proceso para la construcción de un instrumento para medir variables psicoeducativas, explicando puntualmente cada una de sus siete fases. Los resultados obtenidos indican que el instrumento presenta un nivel de validez y concordancia excelentes; así como, un nivel de confiabilidad Muy alto. Se concluye que se cuenta con un instrumento de medición válido y confiable para medir la implementación de STEAM con un enfoque en la indagación para el aprendizaje del sistema solar en la educación primaria y que es apta su aplicación para el que fue diseñado.

**Confiabilidad, Validación, STEAM, Indagación, Educación Primaria, Instrumento de medición**

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**Introduction**

In educational research, it is essential to define variables to study human behavior, through measurement instruments; Hernández and Mendoza (2018) define a variable as “a property or concept that can vary and whose variation is susceptible to being measured or observed […] and that can be recorded by a measurement instrument” (p. 52), for these authors, a measurement instrument is one that “records observable data that truly represent the concepts or variables that the researcher has in mind” (p. 228). For Best (1973), measuring instruments are like material objects through which data can be acquired to analyze them, in order to verify the hypotheses of a research (cited in Ruiz, 2013, p. 41).

The measurement instruments designed must have reliability, validity and objectivity; Reliability refers to the fact that, if the designed instrument is applied to the same individuals on several occasions, it should yield the same results, therefore, they will be coherent and consistent; Validity refers to the fact that the designed instrument must truly measure the study variable, this is achieved through content, criterion and construct validity; Objectivity refers to the understanding presented by the instrument designed for the people who administer, rate and interpret it (Hernández, Fernández and Baptista, 2010).

Some authors also consider within the validity of the instruments, validity by expert judgment, which consists of the review of the construct of the instrument, through qualified voices or group of experts on the subject (Hernández, Fernández and Baptista, 2010; Luna, 2015).

**From STEM to STEAM**

With the advancement in science and technology, pedagogical strategies have emerged that contribute to the promotion of these two areas in various countries, one of these is STEM from the acronym Science, Technology, Engineering and Mathematics created by the National Science Foundation (NSF), to train creative and critical people using technology (Pastor, 2017, cited in Robles-Moral et al., 2022).

In 2009, in the United States this teaching strategy was implemented through the interdisciplinarity of these fundamental areas for scientists and engineers, focused on solving technological problems. Currently, the Arts and Humanities have been added to these in this interdisciplinary proposal, adding the A to STEM, thus creating STEAM (Meza and Duarte, 2020; Perignat and Katz-Buonincontro, 2019, cited in Silva-Hormazábal et al., 2022).

Ortiz-Revilla, Greca and Meneses-Villagrá (2021) analyzed the effectiveness of integrated STEAM education, as a possible way to improve the development of skills in the primary education stage, responding didactically to the complexity of today's world, stating that the development of competencies requires a radical change in the way in which teachers and students conceive the teaching and learning processes, therefore, they propose that integrated STEAM education is one of the potentially most useful and highly beneficial methodological approaches for the acquisition of competencies. that the society of the 21st century demands.

Campos et al. (2018), state that STEAM allows students to get involved in their training, achieving significant learning for a globalized world that not only requires excellent technical preparation, but also allows future professionals to not only transform and transfer information in knowledge, but also that they can function in multidisciplinary teams, where they face with leadership, critical thinking and creativity the great challenges that arise today in the industry.

**Inquiry Learning**

Bevins and Price (2016) consider that inquiry learning helps develop research skills in students, have control over their learning, increasing their understanding and motivation towards scientific practice to address an increasingly complex real world. This pedagogical strategy allows the development of scientific competencies during the development of activities, such as “experimental design, interpretation of results and argumentation of ideas, answering questions about the process” (Fuentes et al., 2018, p. 575), encouraging the discussion of ideas among students to answer questions posed at the beginning of the activities.

**STEAM with a focus on Inquiry**

One of the important characteristics of STEAM is that it is integrated with active methodologies to have better academic performance of students, therefore, the implementation of a curricular design based on STEAM, which proposes the solution of real problems, will allow the development of students' scientific creativity at an early age (Tran et al., 2021).

One of the approaches used to awaken students' interest in scientific vocations is inquiry learning, because students experience amazement when knowing and understanding the world around them (Gordón, 2001, cited by Vizcarra, 2022), for this, it is necessary to design didactic learning sequences from textbooks (Fuentes et al., 2018) so that students develop scientific vocations in natural science topics.

In Mexico, starting in August 2023, they implement the STEAM inquiry-based learning methodology within free textbooks, to develop scientific thinking in primary school students. It consists of 5 phases for the development of projects, 1) Introduction to the topic, 2) Research design, 3) Organization and structuring of the answers to the specific inquiry questions, 4) Presentation of the inquiry results, and 5) Metacognition (SEP, 2023).

Therefore, the researchers set out to design a measurement instrument to evaluate the implementation of STEAM with a focus on inquiry, based on the previous phases, adding the scientific vocation.

**Methodology**

The methodology to design and validate the measurement instrument was based on Ruiz's (2013), 7 phases for the construction of an instrument to measure psychoeducational variables: 1) determine the purpose of the instrument; 2) decide on the type of instrument to use; 3) conceptualize the construct; 4) operationalize the construct; 5) integrate the instrument; 6) carry out the pilot study; and 7) carry out the technical study.

**Development of the phases**

***Phase 1. Determine the purpose of the instrument***

In this phase, it was determined that the purpose of the instrument would be the evaluation of the implementation of the STEAM methodology with a focus on inquiry, through the activities developed in a didactic sequence where the interdisciplinarity of STEAM and the learning phases were identified by inquiry, following a specific objective of the research project.

***Phase 2. Decide on the type of instrument to use***

Once the purpose of the instrument was determined, it was decided that the type of instrument to be used would be a perception survey with responses under the Likert scale “Very Much, A lot, Regular, Little bit, Nothing”, its design was oriented towards the understanding of 5th grade students on elementary education, in a rural area of the City of Ocosingo, Chiapas, Mexico, using emojis that would draw attention and identify their feelings.


**Figure 1** Instrument responses
*Source: Research Images, 2023*

***Phase 3. Conceptualize the construct***

The researchers conducted a review of the literature to measure the perception of primary school students in the implementation of STEAM with a focus on inquiry; however, some separate instruments were found that were analyzed, but it was determined to design the construct based on from the SEP textbook where they describe the phases of the STEAM inquiry-based learning methodology for learning the Solar System.

***Phase 4. Operationalize the construct***

From the conceptualization of the construct, being the implementation of STEAM with a focus on inquiry, the researchers established that each phase of the inquiry would create a dimension with its respective questions to study it, adding the dimension of scientific vocations.

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| Dimension | Operational definition | Questions |
|---|---|---|
| Phase 1. Introduction to the topic | An introduction to the topic is made, through prior knowledge, identifying the problem to be solved and establishing the questions for the investigation (SEP, 2023). | 1. How much do I know about our solar system? |
| | | 2. Do I know what are the characteristics of celestial bodies, that is, planets, moons, meteors, meteorites found in our solar system? |
| | | 3. Can I identify the different ways to study and analyze the celestial bodies of our solar system? |
| Phase 2. Research design | The development of the investigation is specified, answering the questions posed in the previous phase, explaining the data or information obtained (SEP, 2023). | 4. When I researched our solar system, how clear was the information to look for? |
| | | 5. When I researched our solar system, how clear were I about the steps to follow to obtain the information? |
| | | 6. How much information did I research about the characteristics of the celestial bodies in our solar system? |
| Phase 3. Organization and structuring of the answers to the specific inquiry questions | Conclusions are constructed in relation to the established problem, analyzing, organizing and explaining the data obtained during the development of the investigation (SEP, 2023). | 7. How well can I identify the shapes and colors of the celestial bodies in our solar system? |
| | | 8. Did I know what technology is used to study the celestial bodies of the solar system? |
| | | 9. How well can I differentiate between the different ways of studying celestial bodies, for example, with the naked eye, a home telescope, or a space telescope? |
| Phase 4. Presentation of the investigation results | The results are presented to the group, preparing proposals to solve the problem posed (SEP, 2023). | 10. How much did I learn to handle the types of colors that exist and how to create them? |
| | | 11. Regarding the planet I built, how many characteristics and colors did I apply? |
| | | 12. Regarding the planet I built, how much did I learn about calculating distances to locate the planets in relation to the sun? |
| | | 13. How much did I collaborate as a team to build our giant solar system? |
| Phase 5. Metacognition | A reflection is carried out on the activities developed individually and collaboratively, as well as the achievements obtained and the difficulties encountered during development (SEP, 2023). | 14. How much did I like researching information about our solar system? |
| | | 15. How much did I learn to differentiate the sizes and dimensions of the planets? |
| | | 16. How much did I learn to measure the distances between the sun and the planets? |
| | | 17. Did I like using art supplies to color my solar system work? |
| | | 18. How much did I enjoy building my telescope? |
| | | 19. When I presented my work to my colleagues, how satisfied did I feel? |
| | | 20. How pleasant was it to work with my colleagues? |
| | | 21. How much relevant and important information about our solar system did I learn? |
| Scientific vocations | The vocation of an individual can be influenced by the social environment in which he or she operates (Pantoja, 1992). The vocation in science and technology can be influenced by scientific education based on the contents of educational programs, since attitudes and skills are developed during their professional training (Vázquez and Manassero, 2009). | With the solar system work we did: |
| | | 22. How curious and interested am I in learning what celestial bodies exist in our solar system? |
| | | 23. How much do I observe the sky to see what is happening in space? |
| | | 24. How interested am I in learning about the professions that are dedicated to science and technology to study space? |
| | | 25. Did developing this project allow me to think about what I want to do when I grow up? |
| | | 26. How much would I like to use technology to build things? |

**Table 1** Operationalization of the construct
*Source: Research data, 2023*

### *Phase 5. Integrate the instrument*

In this phase, the final instrument is integrated to determine its validity, the researchers used validity by expert judgment, through the Content Validity Coefficient of Hernández-Nieto (2011), with the participation of 3 educational research experts, where each of them evaluated the criteria: Relevance. The degree of correspondence between the item statement and what it is intended to measure; Conceptual clarity. To what extent the item statement does not generate confusion or contradictions; Writing and terminology. If the syntax and terminology used are appropriate for 5th grade students on elementary school; Scaling and coding. If the scale used in each item is appropriate and has been duly coded; and Format. The way the items and the instrument in general are presented.

The calculation of the Content Validity Coefficient of Hernández-Nieto (2011) is determined by the following formula:

$$CVC_t = \sum \left[ \left[ \frac{\sum x_i / J}{V_{mx}} \right] - P_{ei} \right] \left( 1/N \right) \quad (1)$$

Where:

N = total number of questions in the instrument.
$\sum x_i$ = sum of the scores given by each judge to each question.
$V_{mx}$ = maximum value of the scale used by the judges.
$P_{ei}$ = probability of error for each question.
J = number of judges.

Using Microsoft Excel software, a Content Validity Coefficient of 0.91271 was obtained, placing it at an excellent level of validity and agreement.

| Interpretation of the Content Validity Coefficient |
|---|
| a) Less than 0.60, unacceptable validity and agreement |
| b) Equal or greater than 0.60 and less than or equal to 0.70, poor validity and agreement |
| c) Greater than 0.71 and less than or equal to 0.80, acceptable validity and agreement |
| d) Greater than 0.80 and less than or equal to 0.90, good validity and agreement |
| e) Greater than 0.90, excellent validity and agreement |

**Table 2** Interpretation of the CVC
*Source: Hernández-Nieto (2011), p. 100*

On the other hand, the experts recommended changes in the following questions, which were applied to obtain the final instrument.

| Item | Before | Recommendation |
|---|---|---|
| 2 | Do I know what are the characteristics of celestial bodies, that is, planets, moons, meteors, meteorites found in our solar system? | How well do I know what are the characteristics of celestial bodies, that is, planets, moons, meteors, meteorites found in our solar system? |
| 3 | Can I identify the different ways to study and analyze the celestial bodies of our solar system? | How much do I know about the instruments and techniques used to study the celestial bodies in our solar system? |
| 8 | Did I know what technology is used to study the celestial bodies of the solar system? | How much do I know about the technological instruments used to study the celestial bodies of our solar system? |
| 17 | Did I like using art supplies to color my solar system work? | How much did I like using art supplies to color my solar system work? |
| 25 | Did developing this project allow me to think about what I want to do when I grow up? | When developing this project, how much did it allow me to think about what I want to do when I grow up? |

**Table 3** Recommendations for writing questions
*Source: Research data, 2023*

***Phase 6. Conduct the pilot study***

To carry out the pilot test, a small representative sample of 20 students was determined with conditions similar to the sample chosen for the final study (Vara, 2012), that is, 5th grade students on Rural elementary school, 50% men and 50% women; because the sample chosen for the final study was 40 students, 20 men and 20 women.

***Phase 7. Carry out the technical study***

Once the pilot test of the designed instrument has been applied, the reliability of the instrument is calculated. In this case, being an instrument with polychotomous responses, Cronbach's alpha was applied to measure the internal consistency of the instrument through the RStudio Software version 2023.09.1, obtaining a value of 0.8864, placing it at a Very High reliability level (Ruiz, 2013).

| Range | Magnitude |
|---|---|
| 0.81 to 1.00 | Very high |
| 0.61 to 0.80 | High |
| 0.41 to 0.60 | Moderate |
| 0.21 to 0.40 | Low |
| 0.01 to 0.20 | Very low |

**Table 4** Interpretation of the reliability coefficient
*Source: Ruiz (2013), p. 100*

Based on the previous table, the minimum acceptable value for the Cronbach's alpha coefficient is 0.61, however, Celina and Campos-Arias (2005) mention that the minimum acceptable value for the Cronbach's alpha coefficient is 0.70 and the maximum expected value is 0.90, outside of these values the instrument is not considered reliable, on the other hand, alpha values between 0.80 and 0.90 are preferred (Streiner, 2003, cited in Celina and Campos-Arias, 2005).

When performing the correlation analysis of the items (column r.cor) in Table 5, Hernández-Ordoñez and Amador-Licona (2021) mention that if there are values lower than 0.3, the items should be eliminated from the instrument; Therefore, questions P14, P15, P18 and P26 should be eliminated to raise the Cronbach's alpha coefficient; however, the researchers decided to keep them, since there is a completely reliable instrument to be applied in the study.

| | n | raw.r | std.r | r.cor | r.drop | mean | sd |
|---|---|---|---|---|---|---|---|
| P1 | 20 | 0.59 | 0.56 | 0.498 | 0.533 | 3.6 | 0.99 |
| P2 | 20 | 0.37 | 0.38 | 0.349 | 0.298 | 3.4 | 0.88 |
| P3 | 20 | 0.67 | 0.65 | 0.633 | 0.609 | 3.1 | 1.12 |
| P4 | 20 | 0.37 | 0.38 | 0.340 | 0.309 | 3.7 | 0.86 |
| P5 | 20 | 0.55 | 0.54 | 0.505 | 0.504 | 3.9 | 0.79 |
| P6 | 20 | 0.60 | 0.58 | 0.563 | 0.540 | 3.4 | 1.00 |
| P7 | 20 | 0.81 | 0.79 | 0.794 | 0.772 | 3.7 | 1.13 |
| P8 | 20 | 0.72 | 0.72 | 0.728 | 0.682 | 3.6 | 0.93 |
| P9 | 20 | 0.77 | 0.77 | 0.774 | 0.739 | 3.8 | 0.72 |
| P10 | 20 | 0.45 | 0.46 | 0.418 | 0.371 | 4.1 | 1.02 |
| P11 | 20 | 0.33 | 0.33 | 0.314 | 0.258 | 4.1 | 0.97 |
| P12 | 20 | 0.68 | 0.67 | 0.678 | 0.624 | 3.5 | 1.10 |
| P13 | 20 | 0.44 | 0.42 | 0.386 | 0.362 | 4.2 | 1.09 |
| P14 | 20 | 0.14 | 0.17 | 0.094 | 0.088 | 4.3 | 0.66 |
| P15 | 20 | 0.24 | 0.22 | 0.192 | 0.177 | 3.8 | 0.77 |
| P16 | 20 | 0.47 | 0.46 | 0.463 | 0.401 | 4.0 | 1.03 |
| P17 | 20 | 0.29 | 0.32 | 0.304 | 0.252 | 4.8 | 0.41 |
| P18 | 20 | 0.22 | 0.23 | 0.215 | 0.148 | 4.3 | 0.88 |
| P19 | 20 | 0.68 | 0.69 | 0.705 | 0.630 | 4.1 | 0.91 |
| P20 | 20 | 0.63 | 0.64 | 0.607 | 0.576 | 4.1 | 0.91 |
| P21 | 20 | 0.76 | 0.76 | 0.748 | 0.730 | 3.8 | 0.79 |
| P22 | 20 | 0.76 | 0.76 | 0.765 | 0.724 | 4.4 | 0.82 |
| P23 | 20 | 0.68 | 0.70 | 0.704 | 0.648 | 3.9 | 0.72 |
| P24 | 20 | 0.37 | 0.38 | 0.354 | 0.309 | 4.3 | 0.80 |
| P25 | 20 | 0.29 | 0.32 | 0.308 | 0.236 | 4.4 | 0.68 |
| P26 | 20 | 0.15 | 0.18 | 0.139 | 0.114 | 4.7 | 0.47 |

**Figure 2** Item statistics
*Source: Research Results, 2023*

## Conclusions

The design and validation of measurement instruments is not an easy task; it requires an entire process to follow to have a valid and reliable instrument that allows us to obtain data that ensures decision-making in the research carried out.

The questions must be related to the concept of the variable to be measured, to ensure that the instrument is truly measuring said variable. In addition, it must undergo validation, in this case, experts in pedagogical topics were selected to be certain that the questions are correctly designed in their content; On the other hand, a pilot test must be applied to obtain the reliability of the instrument, perform an analysis of the correlation of the items to make decisions to retain or eliminate items that allow us to increase the reliability coefficient of the instrument.

We conclude that, after carrying out the entire process described, there is a reliable measurement instrument to evaluate the implementation of STEAM with a focus on inquiry, which can be applied to learning the solar system in 5th grade students on elementary school.

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