A Comparative Study to Evaluate the Impact of Using the SOLO Taxonomy in Preparing Exam Questions

Cristina M. R. Caridade, Polytechnic University of Coimbra, Portugal
Verónica Pereira, Portuguese Catholic University, Portugal
Inês Borges, Polytechnic University of Coimbra, Portugal

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Abstract
Evaluation is a complex task that requires clear and transparent criteria, ensuring all involved understand it as credible, with educational and social responsibility. However, as evaluation is not an exact science, it is naturally subjective. Do teachers prepare questions covering all levels of complexity? Do they reflect on the knowledge and complexity required for each question? What methods and tools do they use? In higher education, studies on evaluation are few, and in mathematics subjects, they are almost non-existent. Greater reflection on this topic in higher education institutions is needed to deepen knowledge. The SOLO taxonomy, developed by John Biggs and Kevin Collis, in 1982, includes five levels of learning complexity: pre-structural, unistructural, multi-structural, relational, and abstract. The authors have used this taxonomy to assess exam quality and identify cognitive complexity levels needed for assessments. The SOLO taxonomy should be used by teachers to formulate questions, classifying them according to cognitive complexity and assigning appropriate weights in student evaluations. This approach helps identify areas for student improvement, aiming for greater academic and professional success. This paper presents a comparative study of results and discussions based on an evaluation of Linear Algebra program content common to subjects from three different undergraduate programs at different higher education institutions. In the study, students took an exam with questions structured according to an ascending process of cognitive complexity, based on the SOLO taxonomy.

Keywords: SOLO Taxonomy, Assessment, Learning Complexity, Mathematics, Higher Education

Introduction

Written assessments present several challenges for both teachers and students (Bennett 2011; Khan, et al., 2023; Struyven et al., 2003; Zlatkin-Troitschanskaia, et al., 2016). The latter often express a sense of discrepancy between the knowledge they possess on a given subject and what they are able to demonstrate in a written evaluation. For teachers, this difficulty is immediately felt in the creation of questions, as they need to adequately cover the topics being assessed in a clear and fair manner while ensuring the questions align with their intended goals. A written exam, such as the implemented in this study, should therefore be carefully designed to effectively assess students' understanding and skills across different levels of complexity without redundancies. This approach aims to provide useful and detailed feedback to students, which plays an important role in the learning process (Duffield & Spencer, 2002; Henderson et al., 2019), identifying areas that require greater scientific and pedagogical investment tailored to their needs, with the goal of promoting a more targeted and in-depth effort from both teacher and student.

The SOLO taxonomy (Structure of the Observed Learning Outcome) is a valuable tool in educational assessment at all levels of education (Caridade & Pereira, 2024; Svensäter & Rohlin, 2023). SOLO is a methodological instrument developed by John Biggs and Kevin Collis in 1982 (Biggs & Collis, 1982), used to describe the increasing complexity of a student's understanding of a task. It categorizes student responses based on the level of understanding they demonstrate, ranging from simple to complex. It is used in different educational settings to assess and guide the development of student thinking and knowledge (Brabrand & Dahl, 2009; Caridade & Pereira, 2023; Hodges & Harvey, 2003).

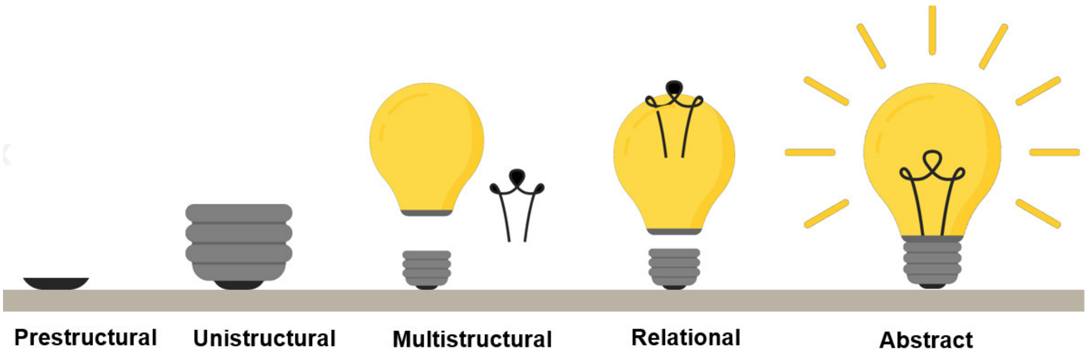

Figure 1: SOLO Taxonomy Levels (own authorship)

According to Biggs and Collis, the SOLO taxonomy consists of five levels as shown in Figure 1, which describe how students process information, from the simplest to the most complex understanding:

1. Prestructural **-** At this level, the student does not understand the task or content in a meaningful way. The response may be irrelevant, confused, or completely incorrect. Knowledge is fragmented, and there is a lack of structure to organize the information.
2. Unistructural - The student demonstrates a limited understanding, focusing on only one isolated aspect of the concept or content. They recognize basic information but fail to connect it with other concepts.
3. Multistructural **-** The student understands more aspects of the task but treats each part separately without making connections between them. They may list or describe multiple elements, but they don't integrate them into a coherent structure.

4. Relational - At this level, the student can integrate and relate various parts of a task or concept, forming a more holistic and interconnected understanding. They start to see how different parts fit together to form a whole.
5. Abstract - This is the highest level of the SOLO taxonomy, where the student can generalize from their understanding, applying knowledge to new contexts or situations. They can think abstractly and make complex inferences based on what they have learned.

In this study, a written assessment was implemented in Mathematics Courses (MC) of three different degrees, namely, Sustainable Management of Cities from the Institute of Engineering of Coimbra (ISEC), Management from the Portuguese Catholic University (UCP) and Management from Coimbra Business School (ISCAC). The work was prepared during the second semester of the academic year 2024/2025 when conducting the examinations of the respective (MCs) at university/institution facilities. The exam questions were prepared based on the SOLO taxonomy and were responded by the 191 Portuguese first-year students involved in the study. The aim was to classify the knowledge acquired by those students and highlight the topics and corresponding levels of complexity where learning needs to be reinforced, with the goal of pedagogically intervening to enhance academic success and increase both teacher and student satisfaction. The topics assessed pertained to matrix calculus, which does not require significant prior knowledge of Mathematics from the students. For this reason, another objective of the study was to compare the results obtained among the three groups of students based on their respective areas of study. Finally, considering the teaching experience of the professors involved in the study, the impact of implementing the SOLO taxonomy in the construction of exam questions, compared to a traditional approach, will be reported.

In this first chapter the introduction is made, in chapter 2 the methodology followed in the construction of the exam questions based on the SOLO taxonomy is presented, and in parallel, a traditional approach to constructing the same questions is also given, in the following chapter the results and discussions and in the last chapter the findings are presented.

Methodology

The assessment of students in mathematics in higher education is subjective, both in terms of the difficulty of the exercises given to students and the content that is assessed. The teacher, based on his years of experience, can identify the most important syllabus for his students' learning and randomly manage the degree of difficulty he places on the exam exercises. In this study, we intend to construct questions for mathematics exams on the contents of Matrix Systems, Matrices, Operations and their applications prepared by 3 teachers from different schools and different MCs. In the construction of the 3 questions presented, two different methodologies were used: methodology A, where the question is constructed in the traditional way, and methodology B, where the questions were constructed in such a way that the students' knowledge was applied in increasing order of complexity according to the 5 levels of the SOLO taxonomy. For example, instead of just asking the student to discuss a linear system with 2 real parameters (*a* and *b*) as represented in question Q1A in Figure 2 (methodology A), the student was asked to initially write the system in matrix form (Q1Ba) and after identifying the values of *a* and *b* for which the system: is possible and determined; it is possible and indeterminate and it is impossible (Q1Bb), according to Figure 2 (methodology B).

Q1A. Consider the system of linear equations $\begin{cases} 2x+y+2z=b \\ x+z=1 \\ 2x+y+az=2 \end{cases}$ $, a, b, \in \mathbb{R}$. Discuss the system in terms of a and b parameters.

Q1B. Consider the system of linear equations $\begin{cases} 2x+y+2z=b \\ x+z=1 \\ 2x+y+az=2 \end{cases}$ $, a, b, \in \mathbb{R}$.

(a) Write the system in its matrix form $AX = B$.

(b) Determine the values of a and b for which the system is:

- Possible and determine.
- Possible and undetermine.
- Impossible

Figure 2: Question Q1, According to Methodology A (Q1A) and Methodology B (Q1B)

The second way of preparing the question consisted of subdividing the initial question into two distinct items, allowing the student to be guided in solving the exercise. The first item has a unistructural level of complexity and the second a relational level, on the SOLO taxonomy scale (Figure 3 on the left). In the first item (Q1Ba) the student only needs to answer one content (1x) while in the next item (Q1Bb) the student needs to have a varied of knowledge and apply it more than once, for example three times (3x) the classification of systems, and in addition it is important establish mutual relationships (represented by arrow in Figure 3) between the information obtained by the Gauss elimination method and knowledge of system classification. In this question the student moves from the unistructural to the relational level as if he were climbing a ladder with a two-landing jump (Figure 3 on the right). Therefore, additional effort will be required on the part of the student when climbing the stairs, which corresponds, in terms of level of complexity, to the difficulty of building interrelationships between different areas of knowledge and their understanding.

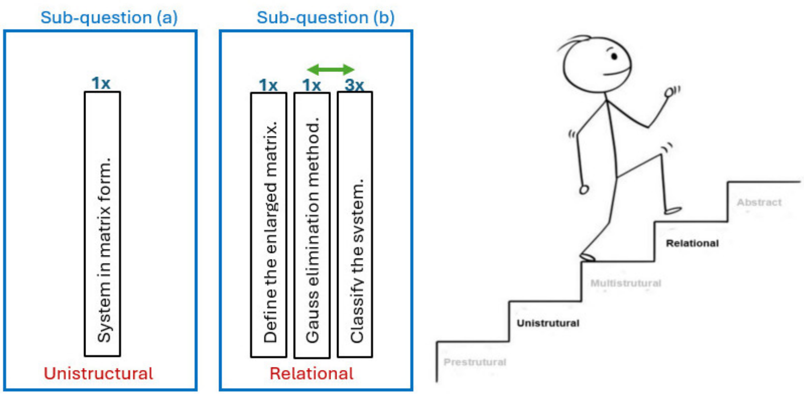

Figure 3: Scheme (Left) and Ladder (Right) of SOLO Complexity for Q1Ba and Q1Bb

In another question (Q2), students were asked to solve the system (the same of Q1), considering *a=1* and *b=0*, if this exists, through the inverse matrix of the system, as shown in Figure 4.

Q2A. Resolve the system $\begin{cases} 2x+y+2z=0 \\ x+z=1 \\ 2x+y+z=2 \end{cases}$ if possible, using the inverse system matrix.

Figure 4: Question Q2, According to Methodology A (question in traditional form)

Where do students experience the most difficulty? Why can't students climb the landings? To answer this doubts, question Q2A was subdivided into 4 smaller items of complexity to be able to find out what level the student can reach. Using methodology B (Figure 5), in the first item (Q2Ba) it is necessary to determine the system solution using the given parameters; in the second (Q2Bb) justify the existence or not of the inverse matrix; in the third (Q2Bc) calculate the inverse and in the fourth (Q2Bd) use the inverse to confirm the system solution obtained in the first item (Q2Ba).

Q2B. Consider the system of linear equations $\begin{cases} 2x + y + 2z = 0 \\ x + z = 1 \\ 2x + y + z = 2 \end{cases}$.

(a) Write the system in its matrix form $AX = B$.

(b) Justify that the matrix A is invertible.

(c) Calculate the matrix A^{-1}.

(d) Determine the solution of the system $AX = B$, using the matrix A^{-1} calculated previously.

Figure 5: Question Q2, According to Methodology B (items Q2Ba, Q2Bb, Q2Bc and Q2Bd)

Figure 6 on the left shows the complexity scheme for each of the 4 items in this question. The level of complexity gradually increased in these 4 items. In the first two items the levels are simpler, only knowledge of one topic is necessary (unistructural), in the third item it is important to have knowledge of two different topics, one of which is applied twice (2x) (multistructural) and in the last item, in addition to knowledge of 3 distinct topics, the relationship between two of the topics is essential (represented by the arrow in Figure 6). The climb between the landings (complexity levels) in the ladder is smoother and more gradual, as shown in Figure 6 on the right.

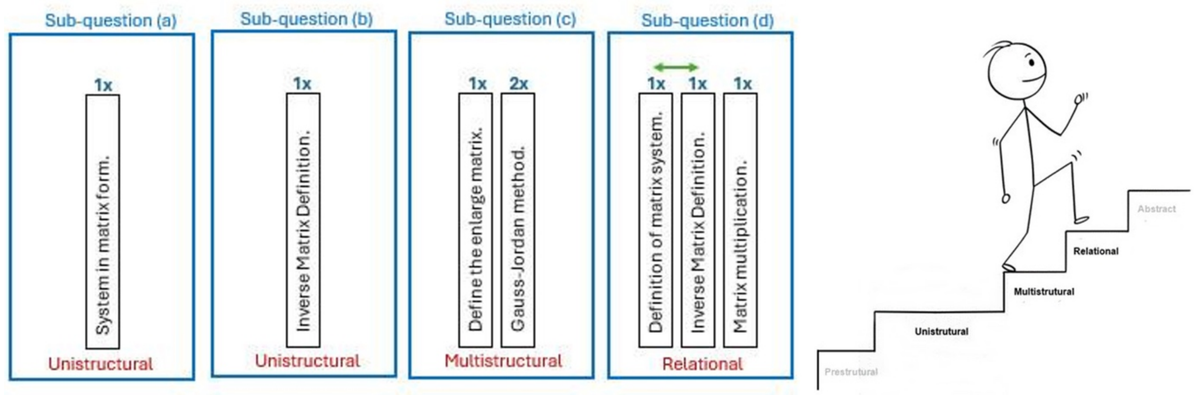

Figure 6: Scheme (Left) and Ladder (Right) of SOLO Complexity for Q2Ba, Q2Bb, QB2c and Q2Bd

A third question, posed to students, was also constructed using the two methodologies A and B. In Figure 7, the question in a traditional form (methodology A) and in Figure 8, the question divided into 4 items (methodology B).

Q3A. Solve the matrix equation $D^T C^{-1} + X^T (C^{-1})^T = D$ with $X \in M_3(\mathbb{R})$, where $C = \begin{bmatrix} 2 & 1 & 2 \\ 1 & 0 & 1 \\ 2 & 1 & 1 \end{bmatrix}$ is a symmetric and invertible matrix and $D = \begin{bmatrix} 1 & 0 & 0 \\ -1 & 0 & 1 \\ 0 & 1 & 0 \end{bmatrix}$ is an invertible matrices.

Figure 7: Question Q3, According to Methodology A (question in traditional form)

In the traditional form question, students are asked to solve the given matrix equation with respect to the matrix *X*, knowing that the given matrix *C* is symmetric and invertible, and the matrix *D* is invertible. This question covers different knowledge and the interconnections between them, forcing the student to integrate different areas of knowledge and develop critical and analytical thinking. When the question is presented according to methodology B, four items are considered, referring to aspects that are slightly more abstract than those described in the previous questions and, as such, are more challenging for students to solve.

Q3B. Consider the matrix equation $D^TC^{-1} + X^T(C^{-1})^T = D$ with $X \in M_3(\mathbb{R}), C = \begin{bmatrix} 2 & 1 & 2 \\ 1 & 0 & 1 \\ 2 & 1 & 1 \end{bmatrix}$ and $D = \begin{bmatrix} 1 & 0 & 0 \\ -1 & 0 & 1 \\ 0 & 1 & 0 \end{bmatrix}$ invertible matrices.

(a) Justify that C is a symmetric matrix ($C^T = C$).

(b) Check equality $(D - D^TC^{-1})^T = D^T - C^{-1}D$, using suitable properties.

(c) Solve the matrix equation given in order to the matrix X and show that $X = CD^T - D$.

(d) Based on the previous item, calculate **only** the element in position (3,2) of the matrix X.

Figure 8: Question Q3, According to Methodology B (items Q3Ba, Q3Bb, Q3Bc and Q3Bd)

The first item, being the simplest (unistructural level), asks the student to calculate the transposed matrix and verify that it is symmetric, indicating its definition (Figure 9 left). At the second item, the student is asked to apply properties between matrices at an abstract level, using only unknowns (letters) in their resolution. The difficulty is greater, since the issue is at a relational level and at the third item, the complexity is even higher because although the level of the Solo taxonomy is the same (relational) the requirement for knowledge and skills to be used and interconnected by the students is more demanding, as can be seen in Figure 9 left. Finally, at the fourth item, the complexity decreases a little and the student is asked to show their knowledge based on the previous items. This question, at the multistructural level (Q3Bd), becomes complex, as it is conditioned on the student solving the previous question, which is why it was asked last. The student, when climbing the SOLO complexity stairs, will have to jump a level between the unistructural and relational and then remain a little longer at this level, since the third item still belongs to this level and finally descend to the lower level in the last item (Figure 9 right).

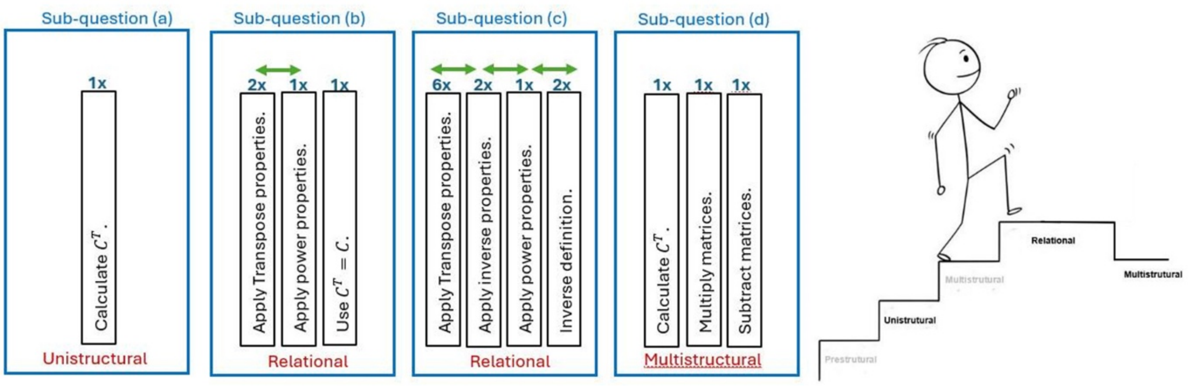

Figure 9: Scheme (Left) and Ladder (Right) of SOLO Complexity for Q3Ba, Q3Bb, Q3Bc and Q3Bd

To investigate the more complex behaviour and capabilities (according to the SOLO taxonomy), developed throughout the students' teaching and learning process, the three questions described above were proposed in the assessments. The questions were selected based on their relevance to the objectives of this study, and analysis of the results will allow not only a reflection on student performance, but also the impact of using the SOLO taxonomy in preparing exam questions. The study was carried out in the second semester of the 2023/2024 academic year, with 149 students from the Management Degree at ISCAC, 10 from Management Degree at UCP and 32 students from Sustainable City Management Degree at ISEC. The ratings for these questions were adjusted to the number of questions involved in each of the exams and the weight attributed to the contents in each of the subjects.

Results and Discussions

Assessment of academic performance is a fundamental tool for understanding the effectiveness of teaching methods and the assimilation of knowledge by students. In this chapter, the results obtained by students in the three specific assessment questions are presented, with the aim of analysing the level of learning, understanding and application of the concepts covered. Next, the collected data will be presented, the statistical analysis applied and, finally, the results obtained, which will be extremely important for a deeper understanding of the evaluation process in higher education.

The data were analyzed according to two procedures: a first comparative analysis of the results of all students (from the 3 schools) to the answers to the questions according to the two methodologies applied (A and B) and a second comparative analysis of the results obtained according to the methodology B in relational SOLO level questions in each of the schools.

Comparative Analysis Methodology A Versus Methodology B

In question Q1, at a relational level, represented in Table 1 according to methodology A, only 17.3% of students manage to answer correctly and reach the relational level (82.7% do not reach this level). Regarding the same question according to methodology B, it appears that in the first item (Q1Ba), 88% of students reach the unistructural level (even so, 12% remain at the prestructural level) and in item 2 (Q1Bb) at the relational level, the distribution is: 18.8% prestructural, 9.4% unistructural, 54.5% multistructural and only 17.3% reach the relational level. This shows that more than half of the students can still reach the multistructural level, but many (18.8%) do not respond to anything asked of them.

Table 1: Results Obtained in Question Q1 by the Two Methodologies A and B (in %)

Question	**No-relational**			**Relational**
Q1A	82.7%			17.3%
	Prestructural	**Unistructural**	**Multistructural**	**Relational**
Q1Ba	12.0%	88.0%		
Q1Bb	18.8%	9.4%	54.5%	17.3%

In Figure 10, it can be seeing the distribution of the number of students who reach the levels of the SOLO taxonomy in relation to question Q2. On the left applying methodology A (Q2A) and on the right methodology B (Q2B). In Q2A, 16.8% of students can answer correctly and reach the relational level while 83.2% cannot get there. Using methodology B, it is possible for the teacher to know the distribution of their students' knowledge levels when they answer question Q2. In questions Q2Ba and Q2Bb, both unistructural, students reach the SOLO level with a percentage of 88.0% and 52.9% respectively, and there is a large percentage who do not know the topic covered. In question Q2Bc of multistructural level, 61.3% of students reach the level and 4.7% are at the lower level (unistructural). Regarding question Q2Bd, 16.8% answer correctly and reach the relational level, but 13.6% remain at the multistructural level, 2.1% at the unistructural level and the remaining 67.5% at the prestructural level.

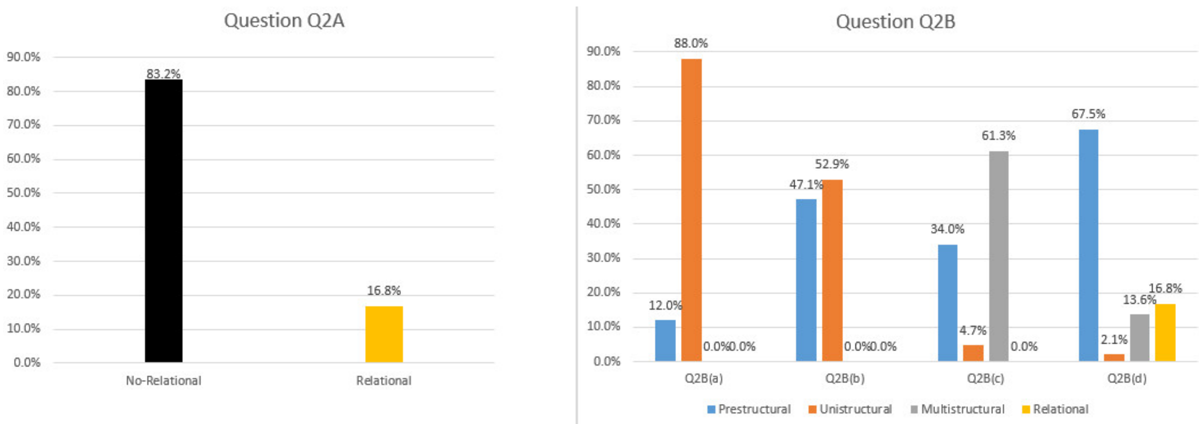

Figure 10: Student Answers to Q2A (Left) and Q2B (Right) According to SOLO Levels (in %)

In the third question (Figure 11) according to methodology A, 19.4% of students solve the question and reach the relational level, but 80.6% do not reach that level. The results obtained with methodology B were: in Q3Ba, 67.5% of students reach the unistructural level; in Q3Bb and Q3Bc, both relational, 22.0% and 8.9% reach this level, with 24.1% and 30.9% at the unistructural level and 10.5% and 8.9% at the multistructural level respectively; in Q3Bd at the multistructural level, 19.4% reach the level, leaving 9.9% at the lower level (unistructural). It is worth mentioning that a large percentage of students do not have any knowledge about the topic, remaining at the prestructural level (32.5% in Q3Ba, 43.5.0% in Q3Bb, 51.3% in Q3Bc and 70.7% in Q3Bd).

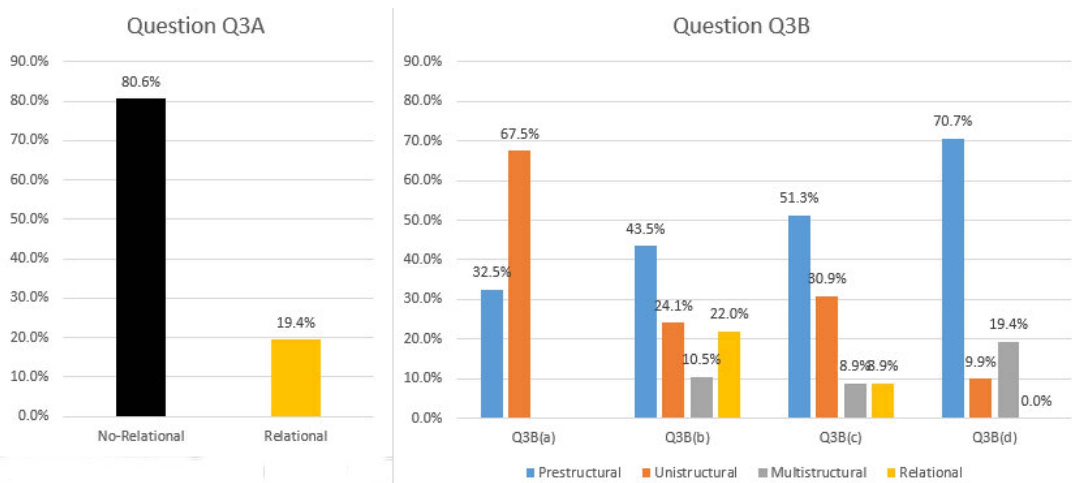

Figure 11: Student Answers to Q3A (Left) and Q3B (Right) According to SOLO levels (in %)

Comparative Analysis Methodology B Versus Schools

The students' answers to the questions presented at the SOLO relational level were analysed, as they are questions with higher levels of complexity and because it is possible in these cases to better observe the distribution of students' knowledge across the SOLO complexity levels. In the first relational level question proposed according to methodology B (Q1Bb), the distributions according to the SOLO levels of the 3 schools involved in the study are represented in Figure 12. In this question the relational level is reached by 16.1% ISCAC, 15.6 % ISEC and 40.0% UCP. Most students in this question are at the multistructural level at ISCAC, unistructural at UCP and prestructural at ISEC. The percentage of students who do not know how to apply or interpret the syllabus assessed in this question is around 10% at ISCAC and UCP and 63% at ISEC.

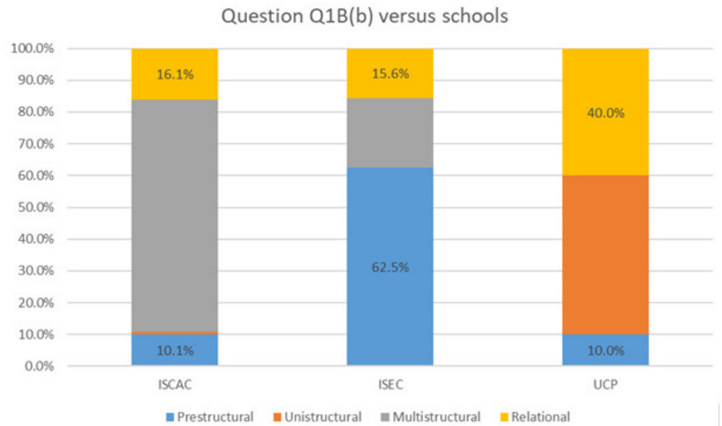

Figure 12: Student Answers to Q1Bb According to SOLO Levels in the 3 Schools (in%)

Regarding the relational question Q2Bd, the results are presented in Figure 13. In this question, students reach the relational level 18.1% in ISCAC, 9.4% in ISEC and 20.0% in UCP. The SOLO level where most students are located is prestutural (63.8% at ISCAC, 87.5% at ISEC and 60.0% at UCP). This issue has the highest percentage at the prestructural level in all schools, which means that students in general did not learn this syllabus.

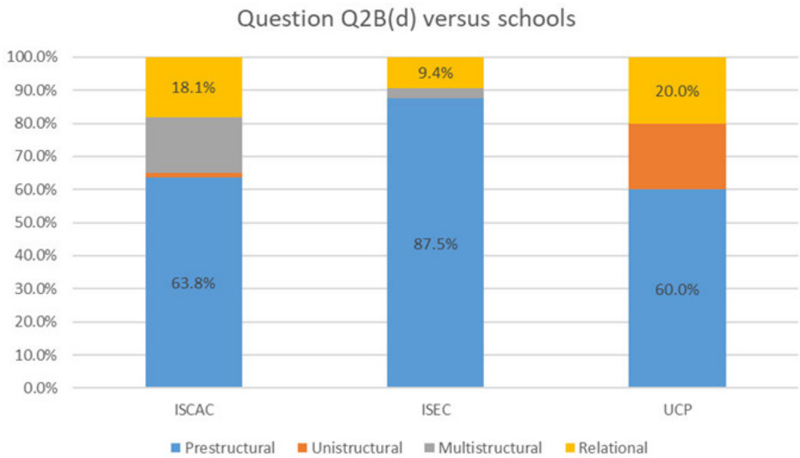

Figure 13: Student Answers to Q2Bd According to SOLO Levels in the 3 Schools (in%)

In the third relational question (Q3Bb), represented in Figure 14, 23.5% ISCAC, 3.1% ISEC and 60.0% UCP reached the relational level of the question. Most students were at the unistructural level at ISCAC, at the prestructural level at ISEC and at the relational level at

UCP. The percentage of students who do not have any knowledge of the syllabus assessed in this question is 36.2% at ISCAC, 84.4% at ISEC and 20.0% at UCP. This question reached the highest percentage (23.5%+3.1%+60.0%=86.6%) of students who reached the relational level among the 4 questions that were analysed in the study.

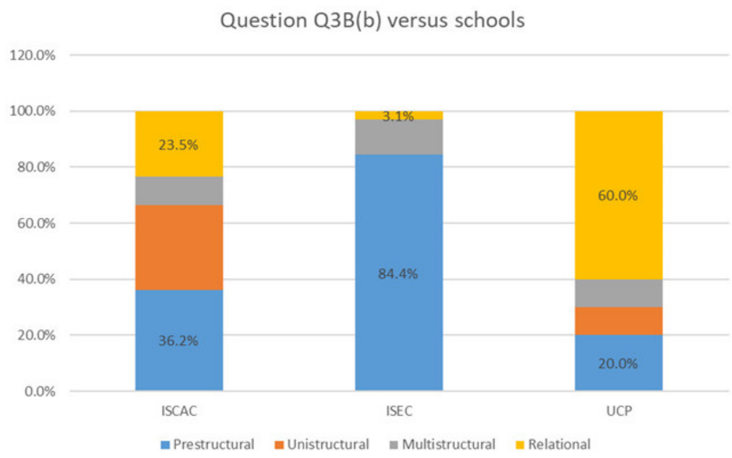

Figure 14: Student Answers to Q3Bb According to SOLO Levels in the 3 Schools (in%)

Lastly, in question Q3Bc (Figure 15), 8.7% of ISCAC students reach this level, 40.0% at UCP and 0% at ISEC. It is worth mentioning that at ISEC no student reached the relational level. Most students reach the unistructural level at ISCAC, the prestuctural level at ISEC and at UCP the percentage of students who reach the relational and prestructural level is the same (40.0%). In this question it was also verified that at ISEC and UCP no student reached the unistructural level.

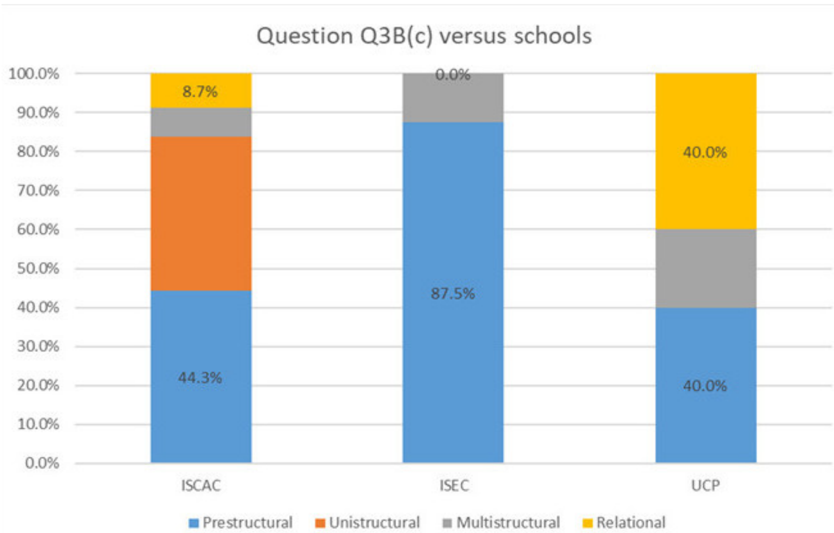

Figure 15: Student Answers to Q3Bc According to SOLO Levels in the 3 Schools (in%)

Conclusion

This study investigates the effectiveness of the Structured of Observed Learning Outcome (SOLO) taxonomy in improving exam question preparation. When comparing traditional question formats with those based on the SOLO framework, there are differences in student performance, engagement, and understanding. The study analyses quantitative and qualitative data collected from three groups of students exposed to two SOLO exam questions, with 3 main objectives: to analyse students' perception of exam performance using questions based on the SOLO taxonomy; evaluate student engagement and success in exam formats based on the SOLO taxonomy and collect feedback from teachers about their experiences with questions based on the SOLO taxonomy.

Based on the analysis carried out and discussed in the previous chapter, it appears that with an increase in the level of difficulty of the items, that is, with an increase in the level of SOLO categorization requested in each item, the number of responses at pre-structural levels and the unistructural level also increases. Which means that the student does not have any type of knowledge about the content of the question or only has knowledge of one of the topics necessary to solve the question. In general, the student was unable to gain knowledge of the different topics covered (multistructural level) nor of the interconnection between these topics (relational level). The evidence is highlighted in the answers to questions Q1Bb, Q2Bd, Q3Bc and Q3Bd, especially in question Q2Bd where less than 20% of students in all schools are at the level required by the item and more than half of these students (in all schools) are is at the prestructural level, that is, more than half of the students know nothing about the topic being asked (in 3 different schools, in 3 different courses and with 3 different teachers). This shows that it is a topic that requires more in-depth analysis and a different way of being approached. It was also evident that the application of methodology B in the construction of the questions allows the teacher to assess whether a student can achieve the level of the question (methodology A), what level of knowledge it is at (methodology B). Therefore, the use of questions according to methodology B allows for greater clarity, facilitating student understanding and ensuring that the connections between the different items are understood. By addressing a more specific aspect of the content in each item, the student feels guided and focused only on that aspect, reducing the possibility of omissions and avoiding some confusion. For the teacher, it is easier to identify which specific aspects the student demonstrates the greatest difficulty or lack of knowledge. In summary, methodology B is a strategy that improves communication and understanding, ensuring that all important aspects of a given program content are addressed in a clear and structured way. It can also be seen that in the comparative analysis of methodology B in relation to the 3 schools, the performance is very similar in the 3 institutions and courses that participated in the study. At UCP, the quality of responses to items is higher compared to other institutions, since the sample of students (5% of the sample) compared to the other institutions in the study is small. In the other two institutions, the results are similar, with that of ISEC being slightly lower since the students in this institution's sample correspond to post-work students and come from non-scientific courses where the presence of mathematical content in their school career is limited to the first years, that is, until the ninth year.

As future work, the authors intend to continue investigating the weaknesses and strengths of question construction according to methodology B, based on the SOLO taxonomy. This comparison must be made in relation to mathematical skills, knowledge of the syllabus and skills acquired by the students, as well as the students' opinion on the clarity and ease of answering the questions and the teacher's opinion on the analysis of the information collected.

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Contact email: caridade@isec.pt