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Development of Lean Six Sigma Competencies through Guided Learning Sequences

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Abstract

Engineering students approaching Lean Six Sigma methodology often fail to develop analytical and statistical competencies, which negatively impacts the adequate development of DMAIC cycle, which stands for the 5 phases of the methodology: Define, Measure, Analyze, Improve, and Control. This problem creates the necessity of improving the efficiency of theoretical – practical content delivery strategies and techniques in the academic formation such that students can be prepared for successful implementation of Lean Six Sigma projects. This evidence-based paper explores the implementation of Guided Learning Sequences, a content delivery technique that combines instruction, practice, and application into real-life inspired problems, to develop data analysis competencies related to the statistical analysis of Measure Phase in Six Sigma.

The study involves 458 engineering students among two years of data collection. Their studying preferences, competencies development, and the effect of the proposed methodology were recorded. Results show a significant effect on the development of Measure phase's data analysis competencies due to exposure to Guided Learning Sequences, with 84% of students achieving a solid or exceptional competence level. Moreover, the study shows that students have preference for learning techniques which combine demonstrative videos and practical problems of real or simulated problems, within individually short time sessions framework. Obtained results contribute to instructional design of new Guided Learning Sequences for developing further Lean Six Sigma related competencies.

Keywords

Higher Education, Lean Six Sigma, DMAIC, Guided Learning Sequence, Disciplinary Competences

Introduction

In Tecnologico de Monterrey, classes are designed to deliver production system's methodologies and frameworks to university students. When referring to Lean Six Sigma (LSS), students are exposed to activities and content intended to develop the competencies required to implement a LSS project, such as data analysis, pattern recognition, competitivity improvement, and problem solution. However, it is a common problem that students fail to fully understand the extent to which statistics is applied in a LSS project, therefore compromising the effective development of competencies and skills.

To overcome this difficulty, courses in Tecnologico de Monterrey continuously introduce novel learning techniques that allow the students to link theoretical content with practical application in real life contexts. This paper explores the implementation of Guided Learning Sequences (GLS) in the Data Analysis class, which explores the basic statistics concepts required to successfully perform the Measure phase of DMAIC.

Literature review

Originated at Motorola in the late 1980's, Six Sigma has evolved into a large collection of tools that in conjunction with a managerial focus, support the efforts to continually improve all the aspects of an organization [1]. According to ASQ, 82% of Fortune 100 companies use Six Sigma to improve their organizational performance by increasing customer satisfaction, reducing defects and cycle time, improving process flow and capacity, and obtaining a high ROI within project implementation [2].

Six Sigma is based on DMAIC cycle implementation, which stands for Define, Measure, Analyze, Improve, and Control. During the Define phase, project management tools are used to clearly state a business problem that must be addressed for improving organizational performance. Then, in the Measure phase, statistical tools such as descriptive statistics, graphical representations, and capacity analysis are used to verify current performance of response variables Y's. Later, during the Analyze phase, response variables are related to possible process inputs X's using statistical tools such as inferential statistics and linear regression so that possible root causes are determined. During the Improve phase, DOE is used to verify optimal levels of critical X's that significantly improve the process' Y's. And finally, Control phase is adequate to sustain improvements by assuring that the process remains under statistical control and addressing potential problems proactively.

Recently, companies have focused in implementing Lean Six Sigma [3], a data-driven approach to analyze the root causes of the organization's problems and reduce the defects throughout DMAIC cycle and Muda elimination [4]. There are eight basic wastes or Muda [5]: transportation, motion, waiting, rework, over processing, inventory, and overproduction. Lean Six Sigma uses Lean tools, such as VSM, kaizen, 5s, SMED, Poka-yoke, or Jidoka, to eliminate these wastes during each of the DMAIC phases.

Literature shows that a critical factor for success of a LSS project is the creation of knowledge in the organization through socialization, externalization, combination, and internalization [6]. That is, a successful LSS implementation require not only a solid theoretical basis, but application and generation of practical knowledge.

However, many companies fail in obtaining LSS benefits due to a lack of comprehension of project context, and because of strict implementation of DMAIC phases with too much formalization and too little contextualized analysis. This situation often happens when Green Belts and Black Belts are trained to follow specific tools, but not empowered to analyze actual data of the organization [7]. Moreover, recent studies have shown that companies who fail to integrate Six Sigma into organizational goals, end up focusing in small projects not statistically relevant to improve quality [8].

Several authors have approached this lack of contextualized analysis by suggesting novel content delivery strategies for university studies and company trainings. Results has shown that asynchronous learning with a technology basis has a positive effect on students' performance [9] and contributes to competency development [7]. Nevertheless, differentiated modalities for content delivery has been found to be a key factor for asynchronous and virtual learning. When available, learning activities may contribute to students' meta cognition and skill improvement [11].

Literature shows that a methodology called Guided Learning Sequences increases student's performance while reducing stress factors [12], allowing the student to focus in comprehending theoretical and practical basis of the studied topic, instead of memorizing decontextualized content [13]. This methodology consists in a series of elements that provide a context in which concepts may be applied, demonstrate the application of those concepts, and then challenge the student to verify their comprehension. These elements are presented to the student in a sequential manner, by means of an asynchronous content delivery platform, such as a Learning Management System [12].

Purpose of the study

Education model of Tecnologico de Monterrey is a competencies-based framework, in which students are expected to fulfill three dimensions to consider that the competencies has been acquired:

- Knowledge: Concepts, theory, and methodologies.
- Applications: Real life and simulated situations in which knowledge can be applied.
- Values and attitudes: Soft skills required for applying knowledge.

The purpose of this study is to measure what is the impact in students' development when implementing Guided Learning Sequences as a content delivery strategy to learn Measure Phase in LSS. The study is particularly focused in the analysis of a specific skill: understanding collected data to generate scenarios that facilitate decision making. Understanding the key factors that allow students to efficiently develop this competence will enhance the way our courses approach this and other related competencies.

Methodology

This paper presents an evidence-based study performed at Tecnologico de Monterrey. It involves 458 engineering students that were enrolled in the Data Analysis course between 2020 and 2022. This course is focused in data collection techniques and statistical analysis for analyzing processes. Students were exposed to a Guided Learning Sequence that explored basic statistical concepts and its application in a real-life inspired problem. This problem referred to the Measure phase of DMAIC, in which students had to identify the current performance of several Y variables and infer about potential variation sources.

The GLS was located in the Learning Management System (LMS) of the University, allowing the student to access it directly on their personal computers. It was assigned as a mandatory activity of the course and had to be done asynchronously, within a one-week time framework. The structure of the GLS consisted in 23 elements categorized as Contextualization elements, Demonstration elements, or Evaluation elements. As shown in Figure 1, these three types of elements iterated to provide dynamic feedback to the student.

Contextualization elements provided the student information about a real – life inspired problem. Within this study, the problem was based on a cardboard boxes factory, which presented several customer complaints. Students had to inquire what was the current process performance using DMAIC's Measure phase methodologies.

Demonstration elements, on the other hand, provided instruction of how to perform the analysis using two different content delivery strategies: written instructions and step-by-step video. Demonstration was performed on a similar exercise, such that the student could understand the analytical process and perform it with the simulated problem data.

Finally, Evaluation elements asked the student key questions that could only be answered by applying the adequate methodology. The questions' format was multiple choice, and after solving the evaluation element automatic feedback was provided in both cases: if the answer was correct, it explained why it was the correct answer; but if the answer was wrong, it explained why that option was a mistake. The student could repeat them several times until all correct answers were provided, providing the opportunity to rehearse mistaken questions. However, if the student could not provide the correct answer, the GLS wouldn't allow visualization of further elements. To earn a completion grade, students were required to fulfill the complete sequence by exploring the different sections of the GLS, whose sections are shown in Figure 2: a context element, a demonstration element, and an evaluation element.

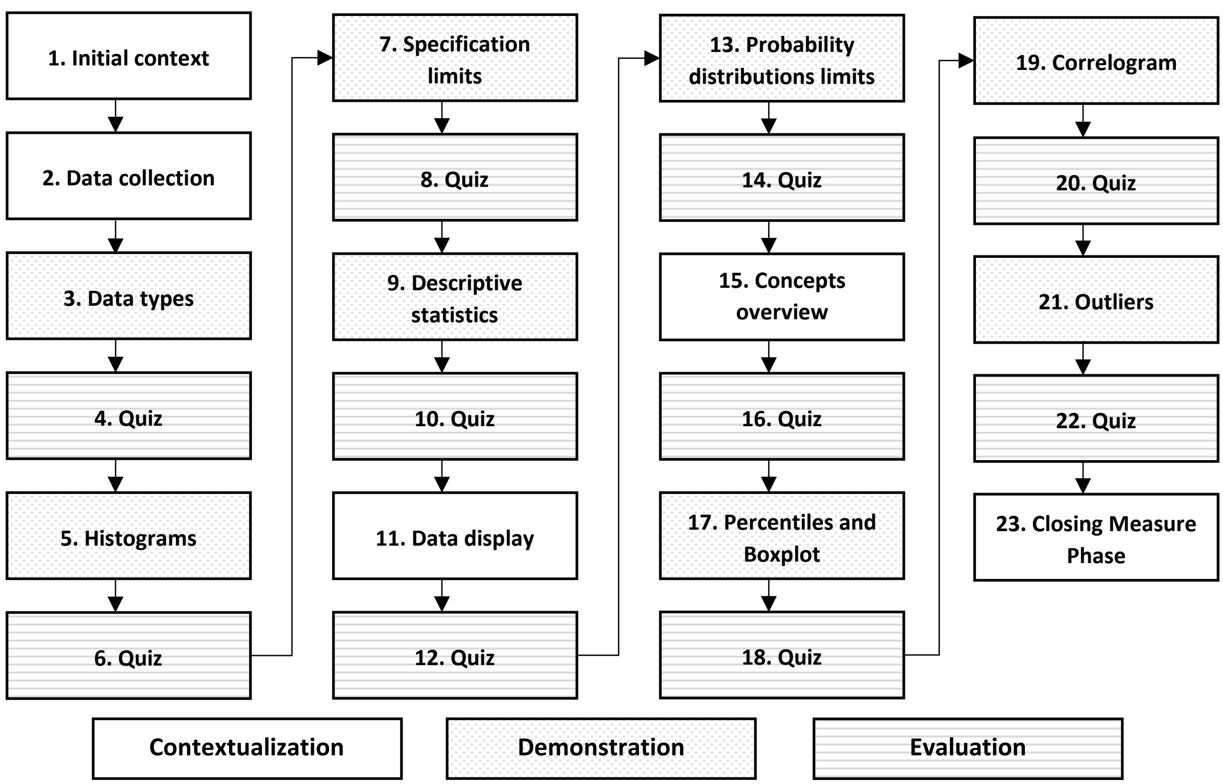

Fig. 1. Guided Learning Sequence for Measure Phase in DMAIC

Once the students had completed the GLS, a competence assessment and a study-preference questionnaire were applied. The competence assessment evaluated the ability of the student to understand collected data and to generate scenarios that facilitate decision making. This competence development was measured with a qualitative rubric that classified students' performance in four degrees: Overachieved, for students who surpassed the expected outcomes of the assessment; Solid, for students who presented evidence of complete development of the competence; Basic, for students who presented evidence of the minimum acceptable performance of the competence; and Underachieved, for students who did not presented sufficient evidence to observe development of the competence.

The study-preference questionnaire focused on capturing the perception of the students of how a study session should be. The questionnaire included elements about content delivery preferences, easiness of collaborative learning, and study time frameworks.

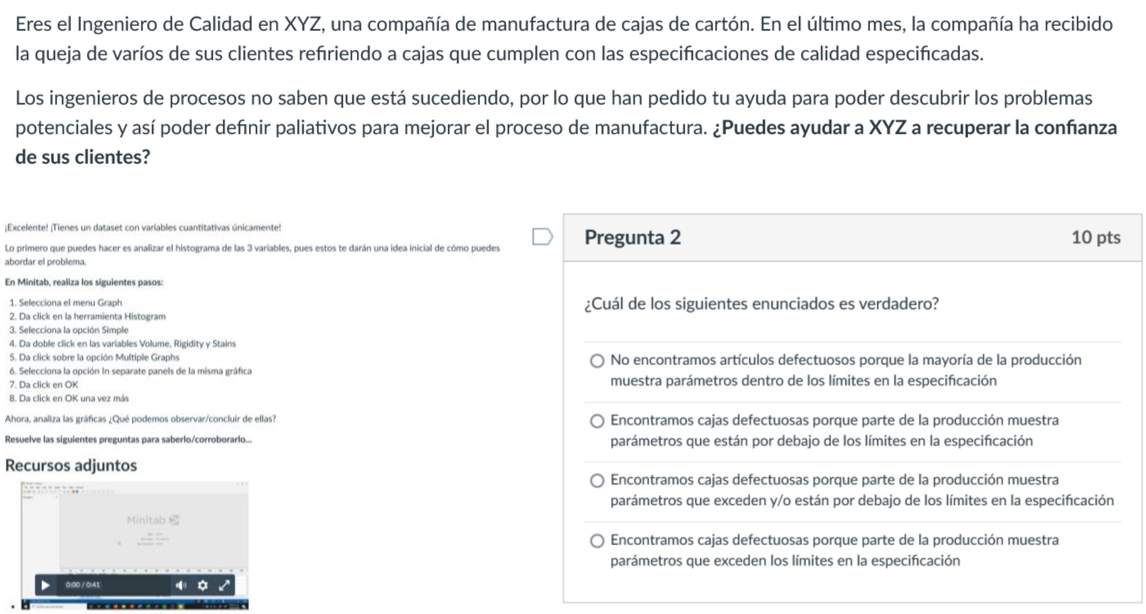

Fig. 2. Guided Learning Sequence screenshots (context at top, demonstration at lower left, evaluation at lower right)

Findings and discussion

In Tecnologico de Monterrey, a competence is understood as the intersection of three dimensions: Knowledge, Application, and Values and Attitudes. Therefore, a student who fulfils a competence must present clear evidence of the three dimensions. Results of the competence assessment performed in this study show that more than 90% of the students developed the course competence, which implies that students understand the topics involved in Measure phase, that can apply those topics with real life data, and that they do it within an ethical framework. As shown in Figure 3, more than 75% of the students presented evidence of overachievement of the competence, that is, they not just applied the Measure phase methodology, but started inferring possible associations with X variables as they should be doing in Analyze phase.

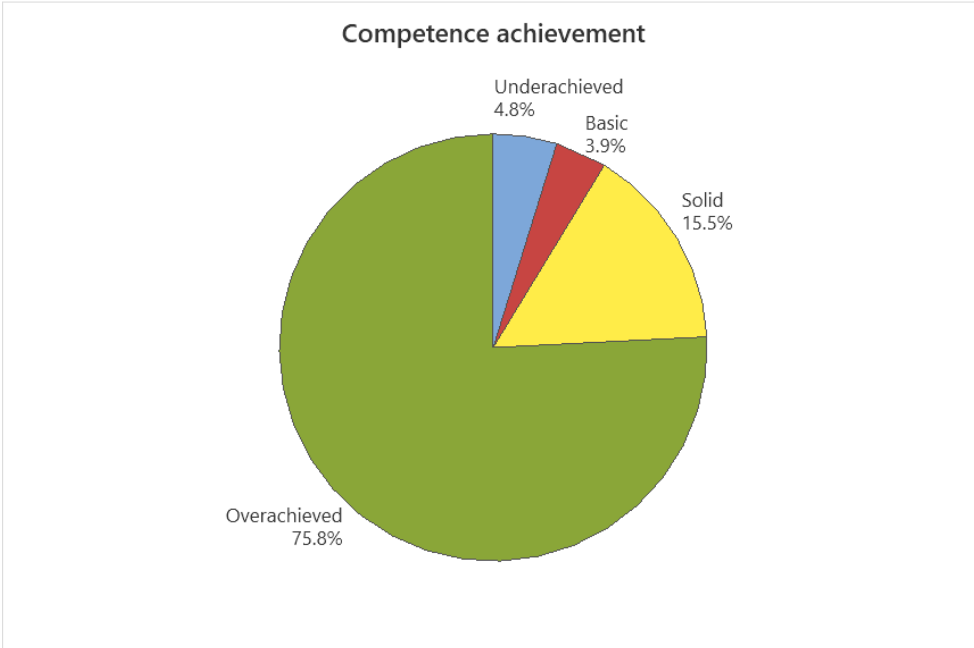

Fig. 3. Competence achievement

Moreover, when comparing exclusively the knowledge dimension of the competence, a significative improvement was found using a Pairwise comparison difference of means hypothesis test. The alternative hypothesis was that student's performance after implementing the GLS was better than before its implementation. In a scale from 1 to 5, students achieved a mean of 1.07 more points after the GLS was implemented, with a confidence level of 95%, as shown in Table 1.

TABLE I. PAIRWISE COMPARISON TEST FOR KNOWLEDGE DIMENSION AFTER – BEFORE GLS

Mean Difference	Std Dev	Std error	85% LCI	T value	P value
1.0742	**1.0723**	**0.0501**	**0.9917**	**21.44**	**0.000**

Both previous results provide empirical evidence of the use of Guided Learning Sequences as an effective technique to help develop competencies, not only involving the knowledge dimension, but including the practical application and behavioral dimension. However, analyzing the perception of the students for better studying practices is important to continue developing GLS for the other phases of DMAIC.

According to the study 87% of the students perceive value in solving the reinforcement quiz, which emphasizes the practical dimension of the competence. However, a slight preference to written instructions over video instructions can be observed, where only 1% of the students totally disliked written instructions, while almost 7% totally disliked video instructions. Figure 4 shows the distribution of the perception of content delivery strategies, where all of them present negative skewness, but video instructions have the highest dispersion.

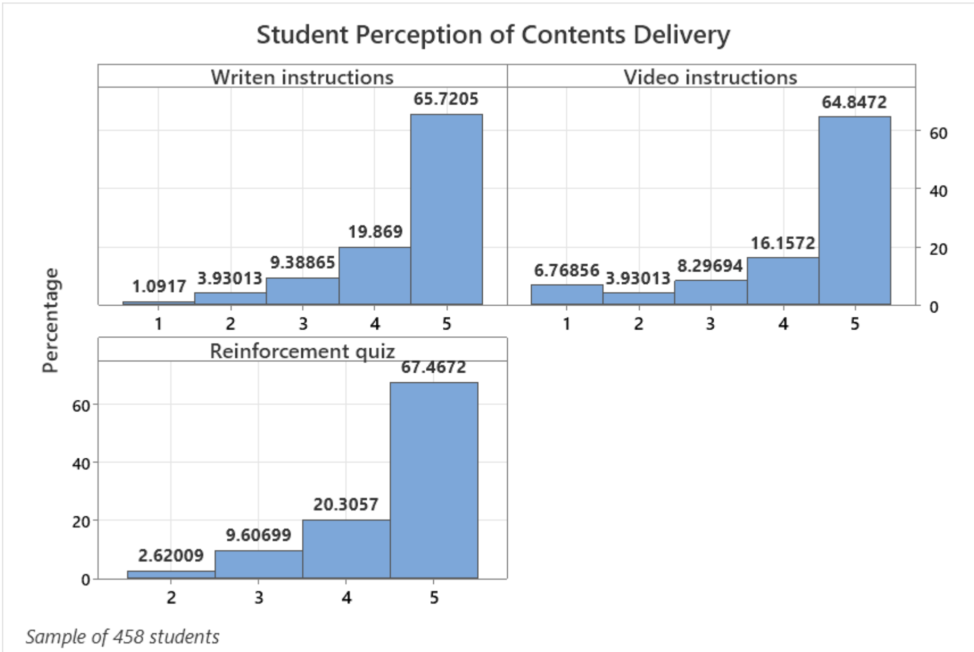

Fig. 4. Perception of content delivery

Similarly to the previous distributions, 80% of the students agreed that the preferred content delivery channels for statistical content should be through demonstrative videos, practical exercises, and simulation of real problems. These channels correspond to the content delivery strategies involved in Flipped Learning and Blended Learning techniques, which supports GLS as a feasible technique for DMAIC learning. In contrast, as shown in Figure 5, only 2% of the sampled students are likely to seek information in traditional sources, such as books or articles, or by solving traditional assignments based on content, instead of in practical application.

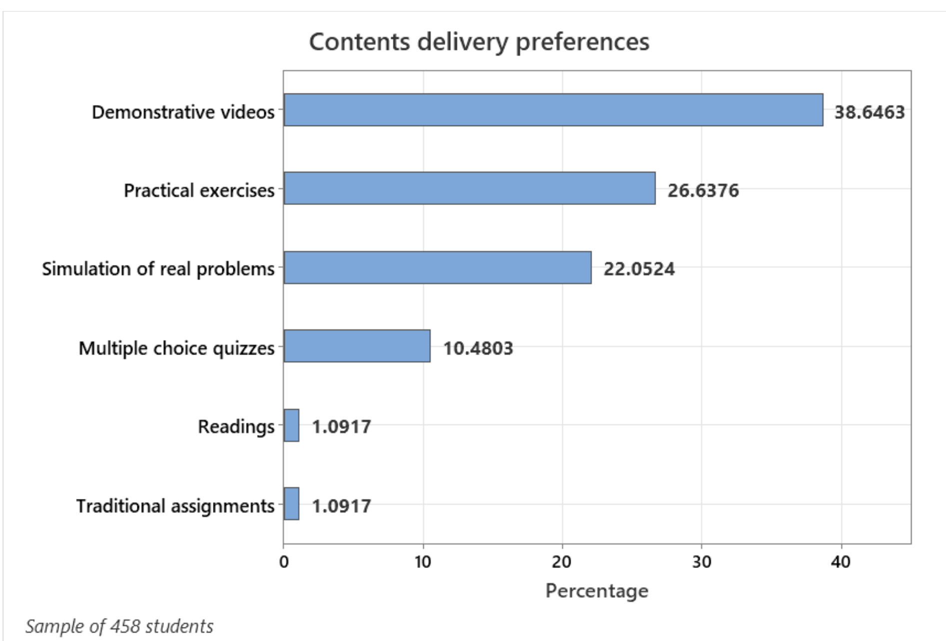

Fig. 5. Content delivery preferences

With respect to the studying preferences, results show that almost 80% of the students prefer to study by themselves when referring to DMAIC concepts, in sessions of one to two hours long. As shown in Figure 6 and Figure 7, techniques such as Guided Learning Sequences should support the possibility of individual learning in a brief period of time, rather than long sessions with collaborative study or teacher paced activities.

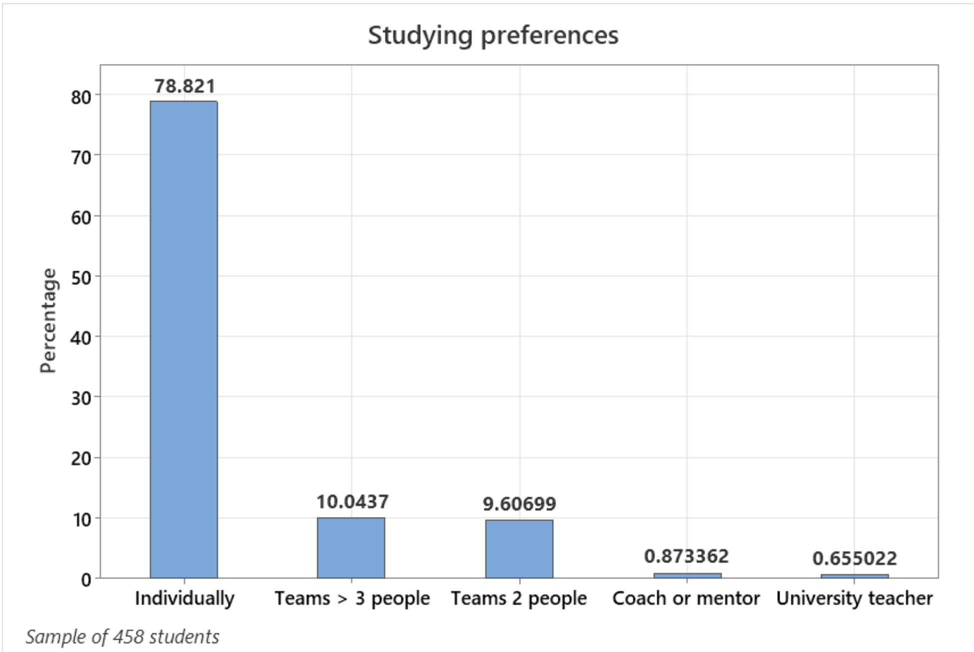

Fig. 6. Studying with other people

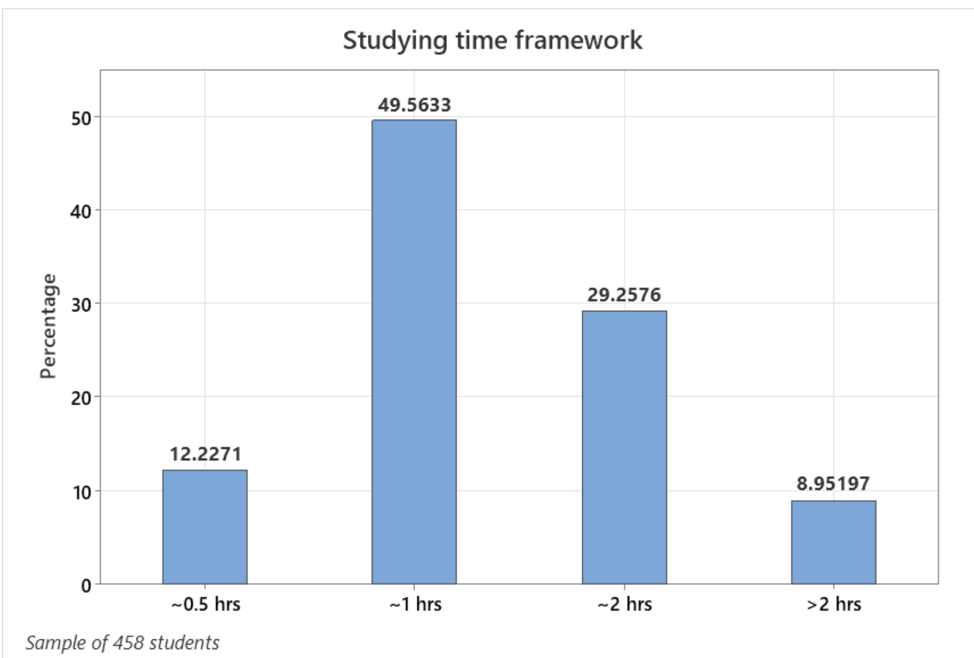

Fig. 7. Studying time framework

Conclusions

This study provides evidence of Guided Learning Sequences to be an efficient technique for content delivery when referring to the measure phase in DMAIC, in which the student can rehearse the theoretical – practical content of the methodology by means of demonstration – application cycles, providing instantaneous feedback in a flexible and individualized way. With its use, students have been observed to improve their knowledge about the statistical procedures of the Measure phase and to effectively develop the competence of understanding collected data and generating scenarios that facilitate decision making.

According to the students' preferences, attractive Guided Learning Sequences should include explanatory videos of the theoretical – practical content, with demonstrations of how to apply concepts into real life problems, clear written instructions of what is expected to be done and automated assessments with instantaneous feedback for the student to verify comprehension of content. These cycles of demonstration – application should be designed to be performed in no more than two hours, including contextualization, demonstration, and evaluation elements.

Future studies will include the application ana analysis of Guided Learning Sequences for other phases of the DMAIC cycle, adapting the methodology to the students' preferences and measuring its impact in the development of competences related to Six Sigma.

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