Spreadsheets Development and Use as a Tool or Obstacle Enhancing Competencies, in the Structural Engineering Learning

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SPREADSHEET DEVELOPMENT AND USE AS A TOOL OR OBSTACLE ENHANCING COMPETENCIES IN THE STRUCTURAL ENGINEERING LEARNING

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Abstract

Context:

In the teaching-learning process related to advanced topics of structural design, it is a common practice to develop spreadsheets (SS) to simplify the numerical routines involved in the calculation of the different elements that conform a structure, following the guidelines of codes applicable in each region or country. This reduces significantly the time used in the numerical routine of the calculations and it gains time for more specialized processes such as distribution and location of structural elements, applicable load systems, structure analysis and the final evaluation of mechanical elements applied on every structural element such as slabs, beams and girders, columns, foundations, etc.

Purpose:

The objective of this paper is to present learning results by means of evaluations and applied polls to students of different courses of structural design in different areas in Civil Engineering and Architecture majors.

a) The evaluations will be applied through traditional exams and quizzes, with some design situations where the students are allowed to use SS and other situations where they are not allowed to use these SS. With the results, we can build a comparative scheme to be studied and analysed.
b) The polls will be applied on-line using Google Forms, where they will be asked perception questions related to performance and learning, comparing the possibility of use SS versus the restrictions on their use. Examples of these questions are:
    - Did you develop and program your own SS or use SS developed by others?
    - How deeply do you know the way the routines work inside the SS?
    - In the change of routine scenario, are you able to modify the SS process to apply change of variables, formulas, and concepts?

Approach:

The design process of structural elements is ruled by codes and handbooks that set specific steps and requirements to evaluate properties and characteristics that provide strength and stiffness, these processes might involve highly elaborated numerical routines, so it is quite common the use of spreadsheets developed to facilitate these procedures.

The common status is that the professor guides the students in the development and programming of their own SS to know the input data, the output values and the results of modifying each value of the input data in every step of the process, nevertheless, there are a lot of external sources available to obtain SS developed by others as a freeware.

The use of these SS developed and programmed by others, frequently have restricted access to the code and it is not possible to establish the inside calculation process or generate process modifications when they are needed due to code or regulatory changes. They are only a mechanization of the process without the possibility of interpretation or modification applying a personal criterion.

When a tool with these capacities and reach possibilities is available, the advantages are immediate in time saving in the developments of the numerical routine and a precision level error free in the numerical process, but we lose the analysis capacity by using the output values without any further analysis of the physical meaning or interaction with other structural elements. We become only data users instead of structural designers.

When a student develops their own SS, they are in the possibility of modifying the programmed routines when it becomes necessary. If they use SS developed by others, the modification of the process turns to be complex because they do not know the base of the programming used in the first place.

We will evaluate if the use of these tools is a knowledge and learning support tool developing structural design competencies, or if it is a tool to make numerical routines easier but losing analysis capacity and abilities and the mathematical and physical meaning of each variable in the structural behavior of every element.

1 INTRODUCTION

In the teaching-learning process related to advanced topics of structural design, the design process, is guided by a group of procedures, formulas and routine numeric and mathematical processes that may become a routine process in the numerical context. These processes and methodologies are often large and with very complex formulas. There are so many variables involved in the formula application and solution that becomes a long time-consumer with many stages where numerical mistakes may happen. As S.A. Oke said: "Research on spreadsheets in engineering education in the last two decades has placed great challenges on educators and other stakeholders to apply this computational tool both theoretically and practically towards improving the teaching-learning paradigm. These recent challenges have forced institutions of higher education to adapt spreadsheets for instructional purposes with its enhancement tools as a means to improve the quality of engineering education. The need for high quality, learning-centred education has therefore made the application of spreadsheets important." [3]

Due to the routine involved in these procedures, the use of SS to reduce the time and error possibilities, is very frequently used. The students, in their structural analysis courses and topics, learn how to mathematically model a structure, their elements, loads and behaviour, and obtain mechanical elements in every structural element. In the structural design courses and topics, they learn how to design an element, beam, slab, girders, columns, footings, etc., using the structural analysis results.

In the teaching-learning process, we show the students how to develop a SS that covers every requirement stated in codes, handbooks, and textbooks, that fully satisfies these procedures. But it is also important to say that there are a lot of freeware SS that the students can find online just by goggling the name of the procedure that they are studying.

We are focusing the paper in this point is where. When we guide and walk the process with the student in the developing of the SS, they know exactly and precisely what is being done in every cell, in every formula. They know the units that must be used or make the proper unit conversion within the process. They know the data needed to start the process and the format they must use to have proper results. When the students use a SS not developed by themselves, then is like a "black box", the data must be in a format that they assume they know, the process and numerical methodology is not available to analyse, and more important, they do not have access to make any modification to the process to be applied in special design cases.

2 METHODOLOGY

The use of SS in education has given the educators, an important tool to reduce time in mathematical processes and focusing on the meaning of each variable involved in the process. Baker wrote "educators are also finding great benefit in tying programming to spreadsheet use, thereby overcoming much of the time spent in organizing data input and output" [2].

In the structural design courses, such as Design of Reinforced Concrete Structures, Design of Structural Steel Elements and Foundation Engineering, we first make an approach to the theoretical concepts, in order to make the students understand the behavior of the structural elements and its importance in the mechanical element transmission throughout the complete structure. Then we proceed to make mathematical procedures to find the equations that fully describe the structural behavior of these elements. Once we have all these equations and formulas, we start looking at

appliable codes such as federal or state laws, handbook and specialized areas specifications that contain restrictions and security factors that must be applied in the structural design process.

Once the structural design process is completed, we start solving several exercises and examples to show how the equations work and how the code restrictions are applied in every case of study. These numerical processes are extended and with a lot of procedural steps. It is common to have flow diagrams to help the students to follow the complete process and do not skip any step.

The students solve several cases applying these flow diagrams and, when they have enough practice, we move to the next step that is to develop Excel SS that implies a deep knowledge of the process but also represents a time saving tool. With these SS, the routine of numerical calculations reduces in time and takes to a very low percentage of error making by hand calculations.

The more experienced the students are in SS programming, the easier is to develop friendly SS to a third-party user and to themselves, to use their own SS long after they have made and used it for the first time.

With the full access available to everyone but particularly to the young people such as our students, they can find a lot of material and SS on-line as freeware to be immediately used in our sessions. Most of the SS available are made by professional engineers that shared them in a diversity of on-line platforms. Some of them are for sale at a low cost. They have valuable information, very nice formatting so they are attractive to the sight but almost every one of these SS, have the procedural formulas and codes blocked at least or hidden to the public's eye. So, they are a *black box* in terms of formulas, codes used and numerical procedures.

These on-line SS are helpful as an introduction to the structural design, but they reduce the cognitive capacity of the students to understand the complete behavior of the structural elements as an individual element and as a part of the complete structure.

Having that in mind, we started this research with the intention to find if the use of the SS, either if they are developed by each student, or shared with other students or obtained on-line, is a positive toll or an obstacle in the teaching-learning process.

The methodology used to run into conclusions on this matter was separated in two different areas:

a) We will apply evaluations using traditional exams and quizzes, with design situations where the students are allowed to use SS and other design situations where they are not allowed to use these SS. With the results, we can build a comparative scheme to be studied and analysed. We will leave the students the choice of using their own SS or to use SS obtained online as a freeware.

b) We will ask students to answer polls. The polls will be applied on-line using Google Forms, where they will be asked perception questions related to performance and learning comparing the possibility of use SS versus the restrictions on their use. These questions are:
   - Did you develop and program your own SS or use SS developed by others?
   - How deeply do you know the way the routines work inside the SS?
   - In the change of routine scenario, are you able to modify the SS process to apply change of variables, formulas, and concepts?
   - In a special design case, where you must go off-routine, do you feel capable to modify your own SS to accomplish the new requirements?
   - In a special design case, where you must go off-routine, do you feel capable to modify others SS to accomplish the new requirements?

3 RESULTS

To obtain the results, we applied the methodology to 39 students from Civil Engineering and Architectural majors. They are listed in several topics such as: Design of Reinforced Concrete Structures, Design of Structural Steel Elements, Foundation Engineering and Structural Engineering Capstone Project.

We have 28 Civil Engineering Students an 11 Architecture Students. All of the students are between the 7^{th} and the 10^{th} semester of their undergraduate studies.

The quizzes applied are a part of the evaluation plan of the subject, they are traditional written tests, applied to all the students enrolled in each subject. The quizzes were graded by the professor and his

interns. The grades are given in order to knowledge applied, alignment with the standards and appliable codes and obtained results. The quizzes are mandatory in the final grade obtained by every student enrolled in the class.

The polls applied were optional. We sent via e-mail and text messages the links to the Google Polls location as an optional invitation. The students choose to answer the poll. We invite 39 students and all of them choose to answer the poll. We opened the poll for 1 week from Monday June 26th to Monday July 3rd, 2023. All the students were enrolled at the different topics for the spring semester starting February 2023 ending June 2023.

3.1 Evaluations and poll results

We will show the two different areas measured and the results obtained as follows:

3.1.1 Evaluation results applied by quizzes and exams.

We applied several quizzes to the students where the must apply the design procedures and methodology that is stated in different codes and handbooks, this evaluation was designed with three different structural elements design situation, where we gave the students the structural analysis results, and they were asked to proceed with the design. In the first exercise they were supposed to solve it by hand without any computer help, only a hand calculator. In the second exercise, they had to solve it using a SS but only if they developed their own. And the third exercise was open to solve it using any legal means, using their own SS or a third person SS obtained as a freeware online.

The results are shown in the following graphics:

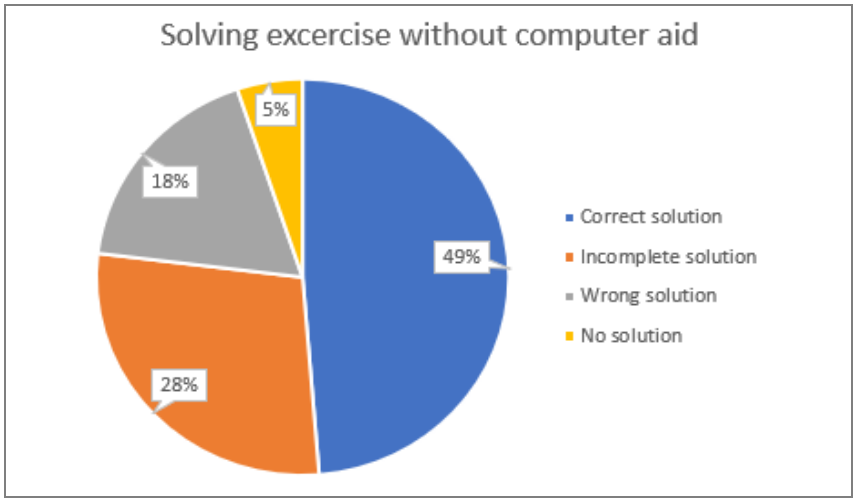

Figure 1. Exercise 1 answers.

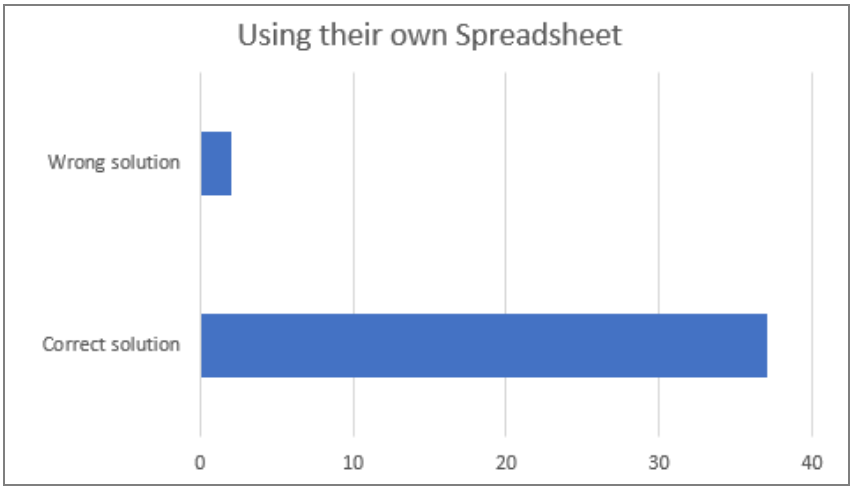

Figure 2. Exercise 2 answers.

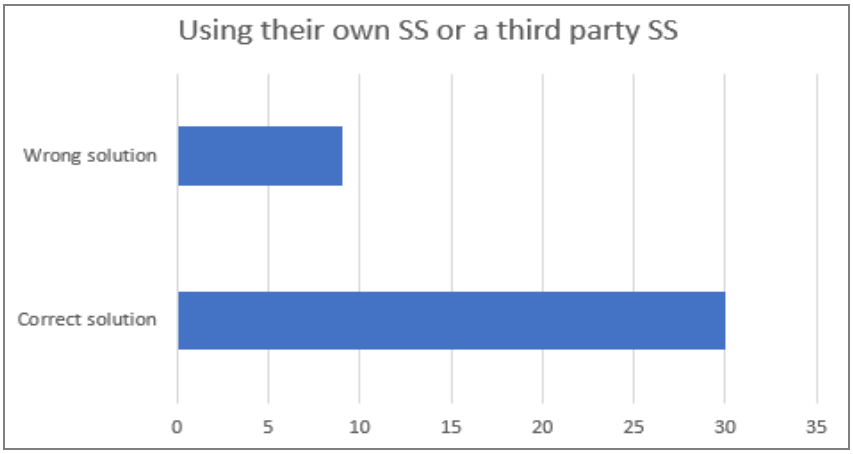

Figure 3. Exercise 3 answers.

In the third design example to be solved, in the basic design code requirements, we modify some specifications to evaluate if the students were able to modify the third-party SS and obtain a correct answer in accordance.

3.1.2 Poll results applied on Google Forms.

The second part of the study is to ask the students to answer polls related to their own perception of the development of their abilities in the design using this kind of aid with the SS.

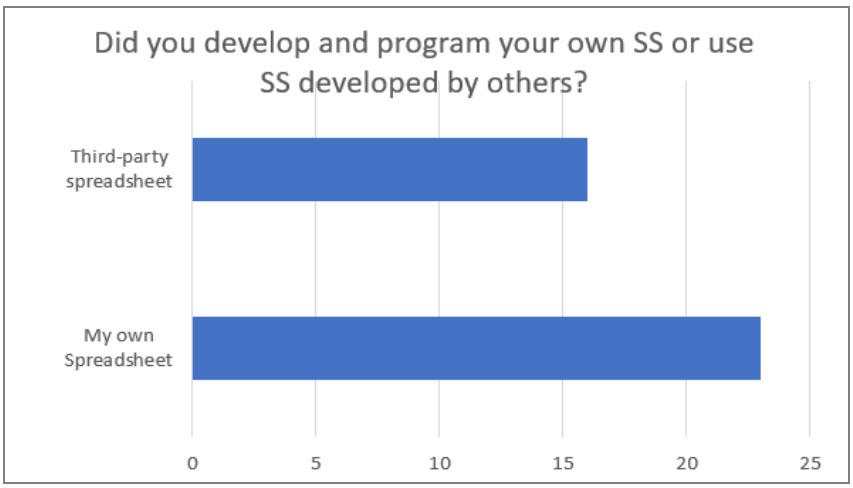

Figure 4. Poll question 1.

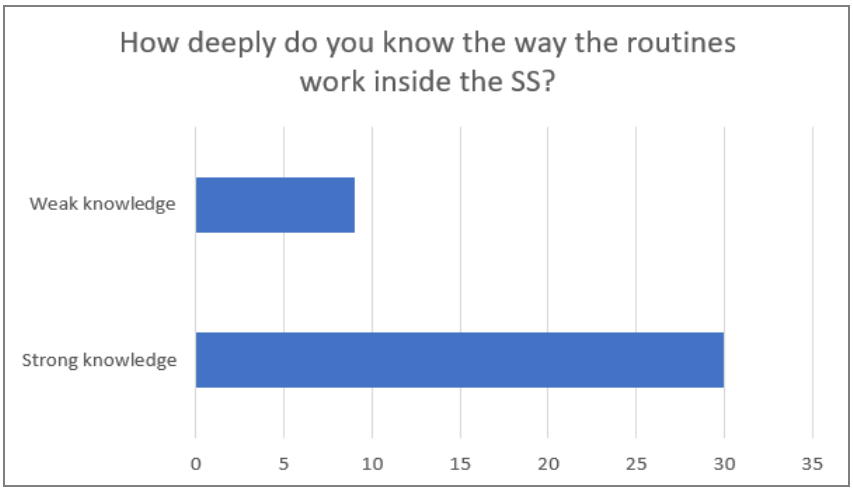

Figure 5. Poll question 2

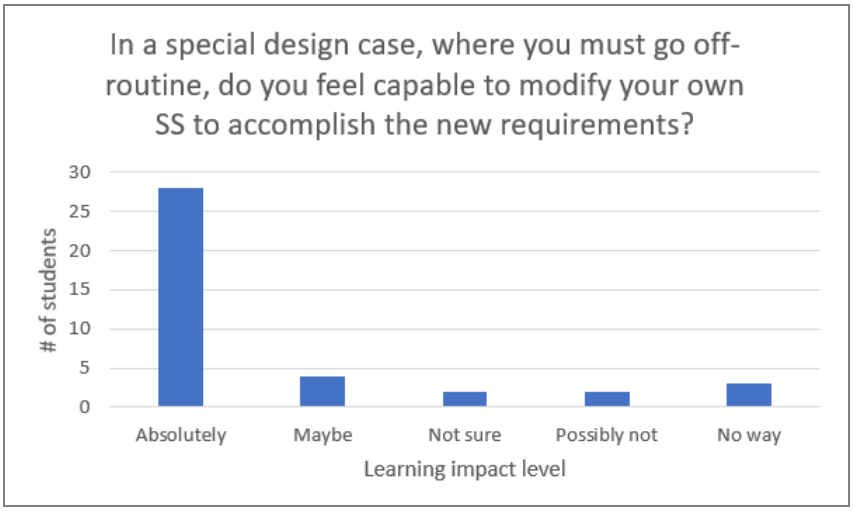

Figure 6. Poll question 3.

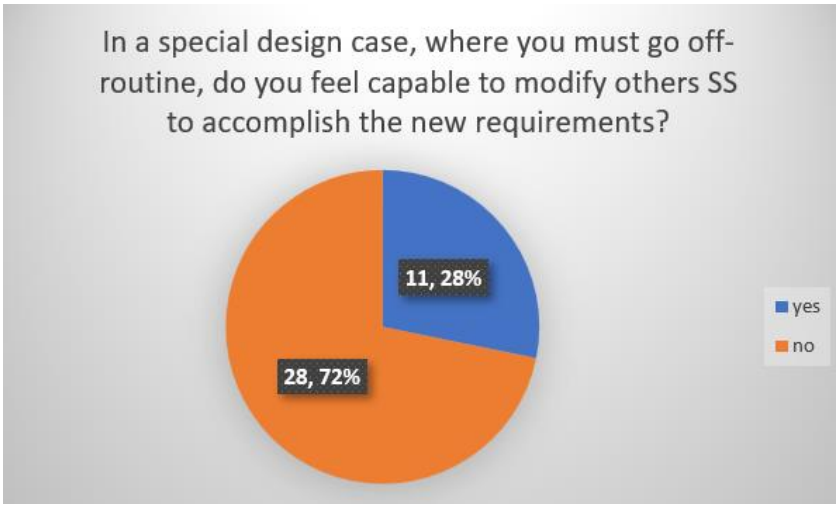

Figure 7. Poll question 4.

4 CONCLUSIONS

According to the results obtained in both, the evaluations and the online polls, we can identify a tendence among the students. They have the knowledge and abilities to solve the design requirements, we can see that in the first evaluation exercise where they cannot use any computer aid to solve. In that situation

77% of the students were able to solve correctly or partially solve the situation presented to them. When the SS are available at the evaluations, the number of students with correct answers increases to 37 out of 39. But when they used a third-party SS the numbers are reduced to only 30 students with the right procedures and answers. We can establish that the students have a better development when they use SS developed by themselves than in the other two possibilities that are not using SS at all or using a third-party SS.

We can make this statement stronger with the student's perception. 32 out of 39 answered that they can modify and adapt their own SS to the new requirements that may happen due to special design cases or modifications in codes and construction or design laws. And only 11 out of 39 think they have the ability and knowledge to make modifications to a third-party SS to accomplish the new requirements. "Hands-on learning is effective in assisting students to grasp what they were taught." [1]

In order to move to further research on this work, we will try to expand conclusions, as Abramovich, Nikitina and Romanenko explain: "A number of interesting patterns can be identified when knowledge and skills are conceptualized as a dual pair. Firstly, in order to acquire knowledge, one has to possess learning skills; put simply, one should be able to learn. These skills will be referred to below as basic skills. Secondly, any new knowledge has the potential to result in the development of skills that bear a professional flavor. Once basic skills reach a certain level of maturity, they can be used in applications. Skills used in applications will be referred to as professional skills. When used repeatedly, professional skills begin affecting individual abilities of the learner by changing and transforming these abilities. Such a chain of transformations in the development of basic skills is inherent to the whole process of education. Thirdly, regardless of their level, most of the basic skills are interdisciplinary in nature. The ability to extend the application of basic skills from one context to another can turn basic skills into what can be referred to as advanced skills. A purposeful application of advanced skills in different contexts can serve as a foundation for the development of new basic skills. By the same token, basic skills can become advanced skills but at a higher cognitive level. In that way, three kinds of skills will be considered in this article: basic skills, professional skills, and advanced skills.[4]

We can arrive to the conclusion that the own developed spreadsheets are a great and helpful tool in the development of structural design competencies, but the use of third-party spreadsheets is an obstacle for the same objective. We must motivate the students to develop their own tools to have a better performance in the structural design activities.

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