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# CYBERBRIDGE: AN INTERACTIVE TOOL TO PROMOTE ACTIVE LEARNING IN STRUCTURAL ENGINEERING COURSES

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## ABSTRACT

Understanding basic concepts and assumptions is a crucial step in the learning process of any subject, yet today it is not always achieved. A change of the current teaching method is suggested in this paper through the implementation of new learning activities based on digital tools. The use of interactive tools has been shown to be an effective method in the field of medicine. Although less frequent, interactive tools could also be beneficial in the field of civil engineering, particularly in structural engineering, where real lab experiments are large, costly and time consuming. By building a small-scale interactive bridge model, the students can have access to a live experiment in the classroom, which enables them to put in practice the concepts learnt during the lectures. This tool seeks promoting a deeper understanding of the subject, thereby increasing the ability of the students to describe different concepts and explain the physical meaning behind the analytical equations taught in structural engineering courses.

**KEYWORDS: Interactive tool, teaching methods, living lab, bridge model, digital twin**

## 1. Introduction

Structural engineering is the branch of engineering that takes care of the design and analysis of a large part of society's civil infrastructure such as roads, tunnels, bridges, dams, harbour piers, etc. Consequently, one of the main objectives of structural engineering courses in higher education is to provide students with the necessary knowledge and tools to be able to design and analyse different types of structures.

Today, most of the design and calculations of structural systems carried out by practising engineers working in the industry are performed using advanced numerical analysis software. These kinds of software are mostly based on the Finite Element Method (FEM), which was developed towards the mid 1950's [1]. The implementation of the first FE software represented a milestone in the field of structural engineering as well as other sectors like the automotive, aircraft and aerospace industries. However, as it is often the case when new opportunities arise, new threats also appeared. In this case, one of the greatest risks that using FE software entails is that users tend to rely too much on the results without analysing critically whether the output generated by the software is feasible. Indeed, FE analysis software are black boxes where users introduce a collection of input data and obtain a certain result. Consequently, to be able to discern whether the obtained results are reasonable, structural engineers must develop critical thinking skills and reach a sound understanding of the behaviour of structural systems and materials.

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Along these lines, in the "samhällsbyggnadsteknik" programme at Chalmers University of Technology, there are two classroom-based courses given during the second and third year, respectively, where students are taught how to perform analytical calculations using simplified models of real structures under a certain set of assumptions with the ultimate goal of enabling them to design simple structures in steel, timber and concrete. However, one of the persisting problems that have been identified in the assessment activities is that most students are unable to repeat a certain task or exercise as soon as minor changes are introduced in the assignment. This is indicative that students fail to grasp the physical meaning behind the equations and tend to memorize procedures without understanding the concepts, meaning they might succeed in passing an exam but fail in reaching the intended learning outcomes. Given that the theory and fundamentals in structural engineering have remained nearly unchanged for the last 150 years, the current problem cannot be attributed to the content of the subject. In trying to identify possible ways in which the learning process of the students could be improved, two main aspects have been considered: the method and the media.

The main teaching method used in basic engineering courses today is still the classic classroom-based lecture. These lectures serve the purpose to introduce new concepts to the students, unveil the meaning and the origin of the equations that are to be used, define the assumptions and limitations of the theories as well as solving doubts that students may have. Whereas this method may not be the most effective way to transmit information as discussed by Bates [2], course evaluations have repeatedly shown that students appreciate those occasions. On the other hand, the teaching activities where students are expected to consolidate the learnt concepts are the tutorial sessions. In those occasions, the students are divided into smaller groups and teaching assistants are responsible to solve a series of exercises on the board. By putting the previously introduced concepts into practice to solve specifically designed exercises, students are expected to assimilate them. However, since the solutions of the problems are readily available online for the students, the incentives to attend these tutorials are low, which is reflected in a noticeable absenteeism.

Regarding the media, its impact on the learning process of students has been a subject of study for many years. In the past, it had been hypothesized that the media did not play any significant role in the student's achievements and media were considered mere channels to carry information, see e.g. [3]. Conversely, subsequent investigations postulated that the media in which instructions are communicated may, in fact, influence the learning process of some students, thereby indicating that the effectiveness of a particular medium will depend on the individual cognitive processes of each student [4]. Today, there seems to be a general agreement that certain media, or combinations of them, can be more effective than others depending on the type of content to be communicated, the context of the lecture or assignment and the type of intended learning outcome, among other factors [2]. This transition has been translated into an increasing amount of complementary support material during the lectures (PowerPoint presentations, videos, clickers). On the other hand, tutorial sessions have not been developed accordingly, and consequently they are currently relying basically on what teaching assistants say and write on the board. Thus, it seems that the tutorial sessions retain the largest potential for development.

Additionally, as recently pointed out in an opinion article published in a Swedish online news website [5], one of the causes of the high number of dropouts in engineering compared to other

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subjects is that the content of the courses do not match the students' expectations. This situation could be partly due to the large amount of math courses that students need to go through during the first year, but it may also be attributed to a missing link between theory and real-world applications in more subject specific basic courses.

A typical tutorial exercise is presented in Fig. 1, where a schematic structural model depicts a simply supported beam, represented as a rectangle, which is subjected to a series of distributed and point loads drawn as arrows. Although this symbology is common to the field and important for students to learn, it is also understandable that some of them may miss the connection between the model and real structural members.
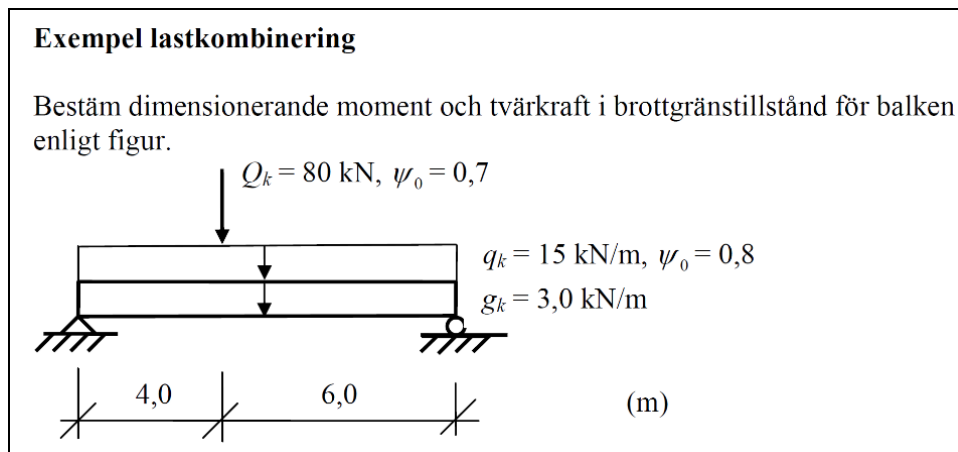


**Exempel lastkombinering**

Bestäm dimensionerande moment och tvärkraft i brottgränstillstånd för balken enligt figur.

$Q_k = 80$ kN, $\psi_0 = 0,7$

$q_k = 15$ kN/m, $\psi_0 = 0,8$

$g_k = 3,0$ kN/m

4,0    6,0    (m)

**Figure 1. Example of calculation exercise solved during tutorial sessions in a structural engineering course**

The aim of this paper is to devise a new type of learning activity that will promote a deep learning approach among the students regarding the fundamentals of structural analysis. The main objectives of the learning activity are: (i) to challenge the critical thinking ability of the students by providing a live study-case application and (ii) to create a tool that students can use to explore and deepen their knowledge in the subject in an easy and intuitive way. Additionally, the learning activity should ideally combine an interactive component to favour active learning with a real-world example to raise interest and motivation in the subject, both of which are expected to increase the engagement of the students and ultimately deliver a better learning environment.

## 2. On computer-based interactive tools

The use of digital or computer-based interactive tools in higher education is not something new. Multiple examples exist, particularly in the field of medicine, such as a simulated interactive patient [6], an interactive game-based tool for surgical management [7] or interactive web-based tools for anatomy learning [8], [9]. Although examples of computer-based interactive tools are less common in the field of civil engineering, they can be also found, see e.g. [10,11].

According to Malone [12] the essential characteristics that make instructional computer games (or any other educational activity) fun, can be divided into three main categories: *challenge, fantasy* and *curiosity.* Whereas *fantasy* is mostly relevant for graphic adventure games, the *challenge* and *curiosity* elements of a game refer to the existence of a clear goal the attainment of which is not certain and the right level of informational complexity to create a novel and surprising environment that the user is still able to comprehend. In other words, the *challenge* and *curiosity* can be described as the motivations to fulfil the designated task and to just continue playing for the sake of it, respectively.

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On the other hand, Nielsen [13] affirmed that the satisfaction of computer users is directly related to the user empowerment, thus the main feature a computer-based tool should exhibit is *usability*, or in other words, friendliness of the user interface. However, Nielsen also highlighted that slight touch of *entertainment* can make the user experience more fun, and therefore more engaging. This agrees with the points raised by Ebner and Holzinger [10], who stated that when the task to be performed by the users is repetitive or boring and the goal of the exercise does not provide the sufficient motivation, interactive interfaces can prove useful in delivering a more enjoyable activity. This also explains why score systems and a competitive element make game-based tools more engaging.

## 3. Targeted courses within the project

The intention of this project is to be implemented in different courses along the three years bachelor's program in Civil Engineering at Chalmers University of Technology. In this particular case, three specific courses are foreseen as main target for the presented tool:

- *"Hållfasthetslära"* [14] (Strength of materials)
- *"Bärande konstruktioner"* [15] (Load carrying structures)
- *"Konstruktionsteknik"* [16] (Structural engineering)

The first and second courses, which are compulsory in order to finalise the programme, are given in the second year. The amount of yearly expected students is around 250. Whilst the first course introduces the behaviour of continuum solid materials from a more general viewpoint, the second focus on the application of those concepts under different structural systems made of concrete, steel and timber materials, which are the most commonly materials used in construction.

The last course, *Konstruktionsteknik*, is an elective course and it is considered a specialization course, in which some advanced and detailed concepts related to the structural behaviour and design of structures are given. This course is considered the best alternative for a first implementation of the tool due to different reasons. Firstly, the fact that it is an elective course, implies that implies that the number of expected students is generally much lower than for the other two courses, namely around 60 to 70 students. Moreover, since the course is considered as a preparatory course to access to the mater's programme in Structural Engineering (it is a prerequisite), the motivation and interest of the student in the subject is expected to be higher. In addition, this is the last course of the programme which runs together with the bachelor's thesis. Consequently, the workload of the students can be assumed slightly lower than in other periods of the programme where they have more courses running simultaneously.

## 4. Activity implementation

In the following it is described a development plan for the implementation of the project within the selected course. The implementation is designed by screening the different parts of the course, targeting the most suitable places where the presented activity would provide the most for the students, by identifying which of the Intended Learning Outcomes (ILOs) of the course are matched better. Accordingly, an alignment between the different ILOs and some Teaching/Learning Activities (TLAs) is presented.

### 4.1. *"BOM340 – Konstruktionsteknik"* (Structural Engineering)

*The syllabus of "Konstruktionsteknik"* is currently divided in three independent blocks, which have approximately the same weight in the course content. The first block sets the focus on the design

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of connections between different structural elements and materials. The second block emphasises the study of the behaviour of structural elements, typically beams, under combination of different service limit state loading condition (SLS). Finally, the last part of the course emphasises the study of instability of slender elements.

The second block of the course, SLS of structural elements, is foreseen as the best suited for the initial deployment of the developed tool. This block is, at the same time, divided into three parts, which focus on the three main construction materials, concrete, steel and timber. The sectional behaviour of reinforced concrete sections is studied in detail, from the uncracked linear elastic state to cracked section, under different loading conditions such as pure bending or a combination of bending and compression. Long-term time-dependent effects such as creep and shrinkage are as well included here. Subsequently, steel and timber cross sections are similarly studied, and the different long-term effects also included.

### 4.1.1. Intended Learning Outcomes (ILOs)

The main objective of the intended assignment is to help the students to reach the ILOs of the course faster and more effectively, with the underlying purpose of achieving that the developed knowledge lasts longer and deeper, so the students can apply it further in their development as structural engineers. The course has several ILOs that connect to the taught content, although 6 different learning outcomes, primarily related to the part of serviceability of structures, have been identified as the most relevant for a meaning contribution of the project:

1. To develop capacity for calculating stresses along a cross-section subjected to bending, tensile axial force, compression axial force and a combination of those.
2. To develop understanding of how a reinforced concrete section can be analysed with help of the equivalent concrete cross-section.
3. To develop understanding of how this calculation technique can be derived forward from equilibrium and deformation conditions under elastic behaviour of the material.
4. To develop capacity toto calculate deflections for steel beams accounting for load variations.
5. To develop capacity toto calculate curvature distributions within uncracked and bending cracked concrete cross-sections taking into consideration material compatibility together with concrete shrinkage and creep.
6. To develop understanding of how the deflections of a simply supported beam are influenced of concrete creep and shrinkage together with bending cracking and steel reinforcement curtailment.

### 4.1.2. Aligning Teaching/Learning Activities (TLAs) with the course/assignment ILOs

The intention of this development project is to modify/implement a series of TLAs that should contribute directly towards reaching the aforementioned ILOs. These new learning activities will fulfil the following purposes:

- To activate the students by placing the focus on them instead of on the teacher
- To illustrate theoretical concepts through a live experiment
- To raise the interest and curiosity of the students
- To create a memorable learning occasion

These activities are based on an interactive tool designed as a complementary means during tutorial/lecturing sessions. The interactive tool consists in a small-scale model of a bridge, outfitted

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with sensors, that connected to a computer via a programmable microcontroller board monitors various structural parameters, analyses them and displays them, in real time, on the computer screen. The setup of the activities will encompass three main activities:

*Activity 1 – Interactive quiz using the quiz:* During the first contact of the students with the interactive tool, the teacher is expected to explain the functionalities of the bridge model and the available outcomes. Subsequently, students may be asked to answer, qualitatively, questions regarding the structural behaviour of the bridge, e.g. through a web-based quiz. After every question, instead of simply showing the right answer, the teacher can reproduce the experiment, live, and the result will be displayed.

*Activity 2 – Detailed calculations:* A second subtask would require the students to perform more detailed calculations to give a quantitative description of the structural behaviour of the bridge. By providing the students with information on the geometry, load and material properties of the bridge model, they can perform simplified structural analyses using analytical expressions to calculate parameters such as the internal force distribution (moment and shear), the shape and magnitude of the bridge deflections, as well as the maximum tensile and compressive stress/strain in a bridge-cross section. This task could be carried out in small groups of two to three students, where they should collaborate and help each other to find the right answer. This exercise could be potentially extended by (virtually) modifying the size, load level and material properties in the model to match those of a real bridge and therefore give the students a feeling of real orders of magnitude.

Based on the quantitative results of the different structural parameters, this bridge model could be also used to illustrate the limitations of beam theory and linear elasticity by comparing how analytical calculations differ from the measured values as the assumptions considered in the analyses stop being fulfilled for increasing load levels.

*Activity 3 – Small scale bridge with different materials:* Last, the students would be enabled to modify, by themselves, the input parameters of the bridge model (virtually), to see for example how different materials behave under different loading conditions, i.e. cracking of concrete, yielding of steel, or brittle failure of timber, or how individual parameters influence the general behaviour, e.g. the span length of the bridge, the load, the elastic modulus of the material, etc. By having control over the input parameters, students could freely explore different scenarios and spend more time in what they think is either more interesting or more challenging. In order to guide the students, a questionnaire with a list of possible questions could be distributed.

### 4.1.3. Assessment Activities (AAs)

No specific assessment activities additionally to the activities already settled within the course are planned. The course has three main assessment activities, which will be used to assess the impact of the development project towards the development of the students' skills and reaching of the targeted ILOs. In the following a description of the AAs and how they will be used to assess the implemented task:

*Final exam:* one week after the finalisation of the course the students must participate in a written form exam in which the different parts of the course are assessed. The exam is divided in two parts, theory which represents 40% of the final grade and problem solving oriented exercises that weights the 60% left of the grade. All the course content is asked here, as well the related with the project.

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*Course task:* a significant part of the course is based on a project that elapses in parallel and aligned with the main TLAs of the course. The project is meant to apply the taught concepts in realistic environment, using as a ground material an existing structure. Again, all the course content is asked here, as well the related with the project.

*Quizzes:* at the end of each block a small interactive quiz is carried out. This quiz is used as a TLA and AA simultaneously. The quiz tries to summarise the content seen during the pertinent block depicting the basic concepts that should have been acquired to match the specific ILOs. At the same time, the main teacher of the course uses the quiz to assess in real time the weak points of the students and uses part of the time to clarify the critical questions that presented more problems among the students. Specific questions related to the task are expected to be implemented here.

## 5. Materials

The characteristics and/or requirements for each of the main components used in the development process of the interactive tool, shown in Fig. 2, are the following:

### 5.1. The physical model of the bridge

As one of the essential parts in the project, this element was required to exhibit certain specific characteristics. First, the material used to build up the bridge model had to be flexible (allowing visible deflections), elastic (recovering the original shape upon unloading) and light (to be able to carry it easily). Moreover, the geometry of the bridge needed to be easy enough for hand calculations and relevant to the students whereas the size had to be small enough to be easily transported. Eventually, a polycarbonate bridge representing a 120 mm wide and 800 mm long deck with three 10 mm high girders was designed.
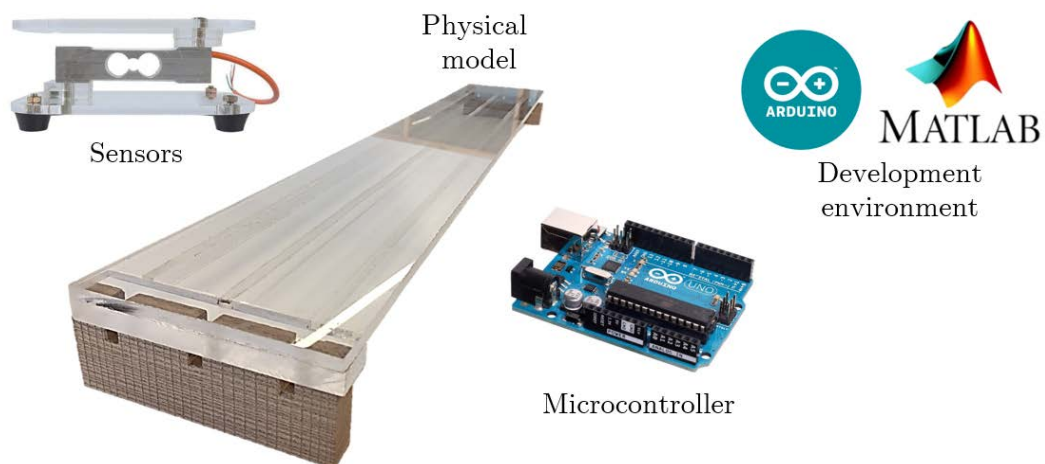


**Figure 2. Main components used in the development of the interactive tool**

### 5.2. The microcontroller

This is the piece of technology responsible to establish a connection between the physical and the digital worlds. Microcontrollers interact with the physical world through transducers, i.e. by reading data from sensors and sending data to actuators. At the same time, this data can be transferred to a computer via a serial port connection or wirelessly. The most commonly known microcontrollers are Arduino, Raspberry Pi and BeagleBone. For this project an Arduino UNO board was chosen. Even though other microcontrollers offer similar or even better features at a lower cost, one of the main advantages with Arduino is that they are ready-to-use, they can be connected to a computer via a USB port and there are many built-in libraries and available examples, as well as a large user community, which makes the initial learning curve less steep.

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### 5.3.  The sensors

The role of sensors is to transform different kinds of stimuli, like light, sound, pressure, etc. into an electrical impulse signal that is received by the microcontroller. For the bridge model, measurements from two parameters were required: forces at the supports and strains in the span. Forces are measured with load cells, which are essentially very precise scales. For this project two HX771 load cells with a max. load of 5 kg each, specifically developed to be used with Arduino UNO boards, were selected. As for the strain measurements, strain gauges with a gauge length of 12 mm have been considered, but not yet implemented.

### 5.4.  The development environment

This is the software needed to, on the one side, send instructions to and retrieve data from the Arduino board and, on the other hand, to process the data and build up the user interface through which the students will be able to interact with the bridge. For these purposes, the Arduino IDE was chosen for the first task whereas Matlab® was used for the remaining part.

## 6.  Results and discussion

A prototype of the devised interactive tool displaying the different components working together is presented in Fig. 3. At this point, only two load cell sensors have been implemented, which are used to define the magnitude and position of the load. Using that information, the remaining parameters are currently calculated based on elastic beam theory. The interface created is capable of displaying results in a clear and organized manner, with real time response. Unfortunately, the development of a friendly user-interface option to modify the geometrical and material parameters of the bridge has not yet been implemented. Nevertheless, the prototype is sufficient to illustrate the concept and its potential to develop further.
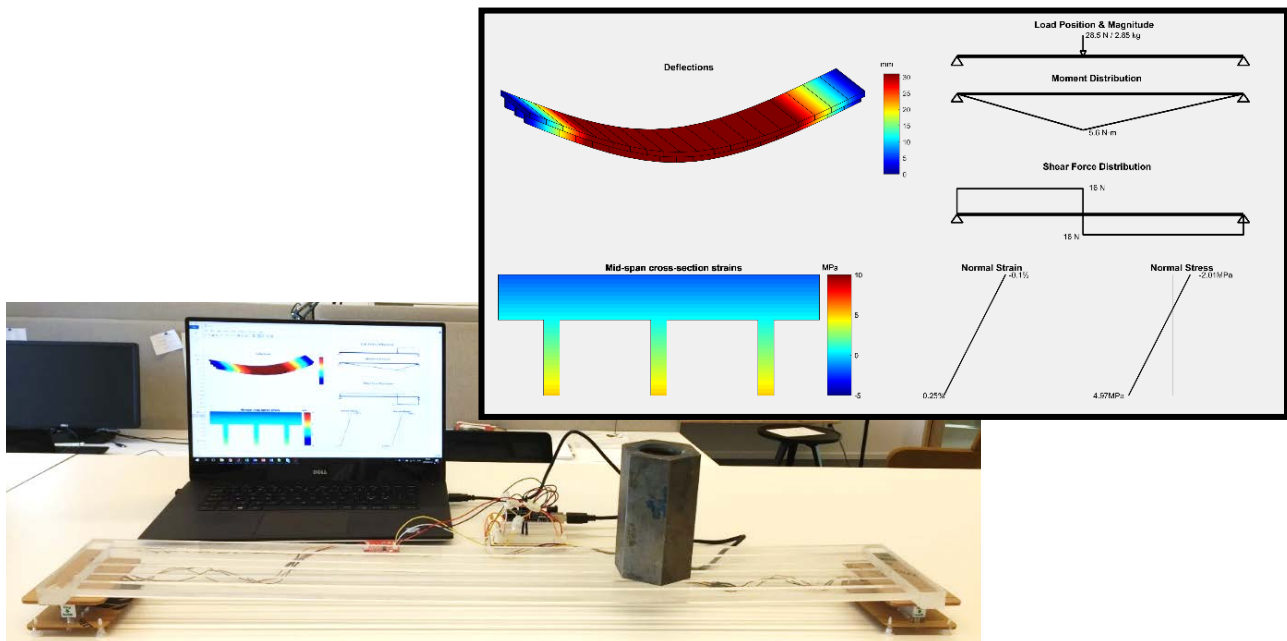


**Figure 3. Prototype of the interactive tool showing the physical bride standing on the two load cells connected to the Arduino board and displaying various results on the screen of the computer in real-time. A screen-capture of the different parameters shown by the model is also included.**

The designed learning activity was also analysed, based on the characteristics that an interactive tool should have (see Section 2). These following points were identified:

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- The *challenge*: a clear goal is stated where, in the main task, students are required to find the right values describing the structural behaviour of the bridge model.
- The *curiosity*: the curiosity of students is prompted by the possibility to explore the differences in structural behaviour that different materials offer through an interactive and attractive interface.
- The *usability*: the interactive tool is based on known symbology related to the field of structural engineering and common navigation tools such as drop-down menus and tick boxes that should be familiar to any computer user.

Furthermore, a group of eight students who had recently taken the *"Konstruktionsteknik"* course for the use of the interactive tool was surveyed. The format of the survey comprised a 15 min presentation where the project, the interactive tool and the intended activities were presented, followed by a questionnaire including several types of question delivered using the online tool [17]. Among other questions, students were asked if they thought this tool could have helped to better understand concepts and increase their interest in the subject, which ILOs of the course could be better explained with the support of the tool, where in the course would be more appropriate the use of the tool and what three words they would use to describe this tool (see Fig. 4).
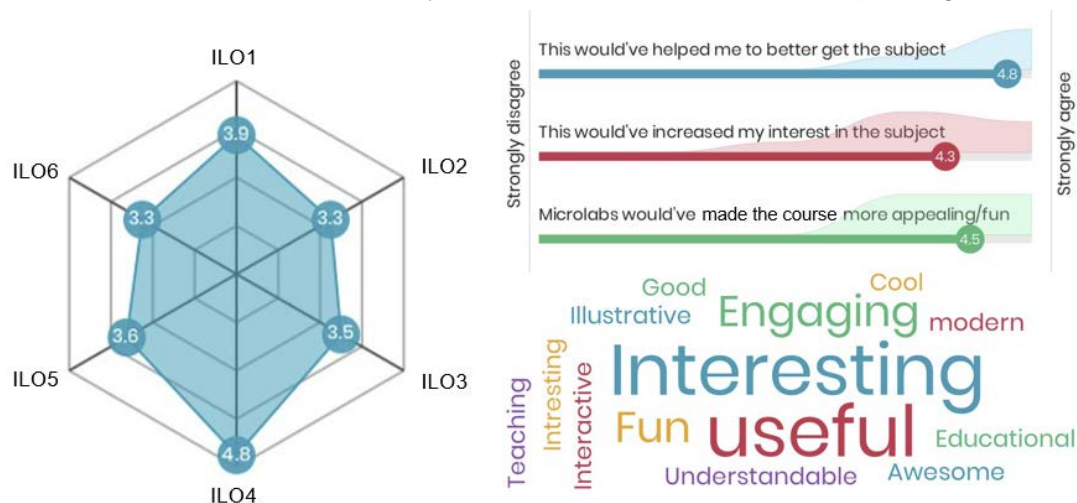


**Figure 4. Example of some of the feedback received from eight students regarding the interactive bridge model. The description of the ILO's can be found in http://goo.gl/Q23d9A.**

As observed, the interactive tool was well received by the surveyed students, who thought that, overall, it had the potential to clarify some concepts while making the subject more interesting and fun. This is also reflected in the most common words used to describe the project: interesting, useful, engaging, fun and engaging. In addition, the students clearly indicated in which part of the course they thought the bridge would be most useful. Further feedback from the students included in which occasions they would rather use the interactive tool, grading of the different proposed activities and suggestions/wishes for further development. The entire questionnaire results can be downloaded at http://goo.gl/Q23d9A.

The results of the questionnaire are a clear indication of the potential of the tool as well as of the need to further develop it to deliver a learning activity that can match the students' expectations. Nevertheless, due to the reduced size of the group of students interviewed and the premature state of the project, it is currently not possible to have a proper assessment of the capabilities of the tool to enhance the learning experience of the students. Instead, the assessment should involve an entire course group, which should be able to interact with a more developed version of the tool.

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The next step is, therefore, to continue with the implementation of the unfinished parts and to devise a new questionnaire to obtain reliable results regarding the efficacy of the interactive bridge.

## 7. Conclusions and recommendations for further development

An interactive tool has been developed to encourage a more active learning approach in structural engineering courses. The aim of the tool is to activate the students and make the subject more appealing, interesting and engaging thereby promoting deep learning among the students. A proof-of-concept has been implemented, showing the viability of the proposed solution, which furthermore has been positively appraised by a group of former students in one of the target courses. Recommendations for further development were received from the students as well as from course peers. An interesting suggestion was to involve the students in the implementation of new features, which could be carried out as specific assignments in more advanced courses or alternatively as a research proposal for a master and bachelor thesis projects.

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