

Introducing High School Students into the Multidisciplinary World of Bridge Construction Using Project-Based Learning

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Abstract: This article presents the application of the problem-based learning (PBL) methodology for introducing the civil engineering task of bridge design and construction to high school students with a multidisciplinary approach. The materials (toy construction system) and methodology of the workshop are first presented. Then, three examples of arch typology proposals are detailed, as an example of the evolution of the students' designs in time while retrofitting the successive editions. A selection of the built structures along with some pictures of their most representative details in the decks and arches are included. Finally, the different experiences obtained from this activity are also reviewed. The objective of this paper is to present the observations of the authors after several years of conducting this workshop with the hope that colleagues from other institutions might benefit from the strategies exposed and adapt them to different disciplines or focus on specific topics. The key observation was that the use of construction toys, which are not usually used by teachers, proved to be a powerful learning tool, the limitations of which can be overcome, and the method used was improved annually to realize the objective. DOI: [10.1061/\(ASCE\)EI.2643-9115.0000022](https://doi.org/10.1061/(ASCE)EI.2643-9115.0000022). © 2020 American Society of Civil Engineers.

Introduction and Objectives

In recent years, the civil engineering field has experienced a crisis owing to the reduction of investments in public works. Therefore, particularly in Spain, civil engineering studies is no longer as popular as it previously used to be. As highlighted by Lozano-Galant et al. (2013), civil engineering schools are adopting different strategies to repopularize these studies among the youth. In this context, the current work is framed as an illustrative activity that demonstrates the role of civil engineers and encourages high school students to select civil engineering as a career.

For the first time since their creation, civil engineering schools have been forced to make their degrees more attractive to students

in order to convince more students to enroll. One of the most favorable strategies adopted by some universities is project-based learning (PBL), which contrasts with the traditional teaching system. PBL encourages students to acquire the abilities required by construction companies by means of a learned focused educational approach in which the student extends previous knowledge to real-world problems through self-directed consideration, research, and practice (Savery 2006).

To overcome the aforementioned new challenge, civil engineering schools are required to be able to implement efficient strategies and focus more effort on engaging and enrolling new students from high school. These students are having to participate in the complex decision-making process of selecting a career in one of the various technical disciplines, which is significantly influenced by ignorance regarding the specific competencies required for each degree. Therefore, in recent years, universities have proposed an increasing number of civil engineering activities such as the design, building, and testing of a bridge built using only spaghetti that spans a specified length, or the construction of a small dome frame that can support a given weight without collapsing while using everyday items.

A team of faculty members of the Civil Engineering School of the University of Castilla-La Mancha thus participated in a project presented by the Energy and Environment Science and Technology Campus (CYTEMA 2020) and applied for funding to participate in the Summer Scientific Campuses organized by the Spanish Foundation for Science and Technology (FECYT 2020). The aim of these projects was to introduce high school students into the world of science and technology and the field of civil engineering in particular. The aforementioned project was aimed at motivating students to discover the daily proximity of the mechanisms that govern bridge construction technologies from a multidisciplinary viewpoint in a fun and intuitive manner (without the loss of scientific rigor). Over three consecutive summers, 32 high school students participated in the project presented herein per year. Throughout the development of the project, the faculty team encouraged the

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students to understand the relationship between science and society and as well as the many areas of knowledge necessary for realizing the design and construction of bridges.

One risk that may arise with this type of activity is the problem described by Lachney and Nieuwsma (2015) as “bait and switch,” because one of the hidden objectives of this type of activity is to bait students into applying for a particular university bachelor course after high school, and the students then find that the bachelor course is not as they expected. However, the authors believe that the PBL method followed by the Civil Engineering School of the University of Castilla-La Mancha is different from the traditional method used in the majority of university engineering courses, which are focused on a fundamentals-first approach, owing to which students spend a large amount of time learning fundamentals instead of being taught how to solve creative design problems. The authors’ civil-engineering-school program includes a number of subjects with open-ended projects (road and railway design, bridge design, and hydraulic canals design, among others), which are based on the principle the authors have used to design the course described in this paper.

Furthermore, since the creation of this program, there have been a number of reports regarding the successful application of this methodology in this school. For example, Aparicio and Ruiz-Teran (2007) reported on the application of the PBL methodology to structural projects, Lozano et al. (2013) analyzed the use of PBL in addressing the challenges of the higher education system, López-Querol et al. (2014) introduced PBL in the study of transportation geotechnics, and Mobarak et al. recently proposed the application of a low-cost image-recognition technique for improving the students’ perception of the dynamic response of small-scale buildings.

The PBL methodology applied in this project is also based on cooperative learning (Johnson et al. 2006), wherein students work in small groups to solve a real-world problem in a specific location, as if they were engineers (Giménez-Sancho et al. 2013). Using this method, the problems that students had in understanding theoretical concepts explained in class were solved by designing of a bridge to scale using something that would not be used in traditional teaching methods (a construction toy). The students also discovered the various scientific and technological challenges associated with designing a bridge as well as the different mechanical and hydraulic tests used for checking that the bridge met the design requirements.

With the main objective in mind, the specific and transversal objectives of the project are as follows:

- Promote the use of the scientific method among preuniversity students for problem solving. The students were given the material and allotted several hours to design and construct a bridge in the experiment.
- Encourage creativity in problem-solving problems by presenting students with attractive challenges such as designing and building a scaled model of a bridge with the longest possible span and that is both robust and economical.
- Encourage and promote the use of multidisciplinary thinking by including the considerations of the different fields of knowledge (such as structural engineering, hydraulics, geotechnics, and construction techniques) required to address a bridge project.
- Strengthen the students’ curiosity as a fundamental tool for efficient learning.
- Provide a medium for the public-service vocation of scientists in general and civil engineers in particular.
- Introduce students to the PBL methodology, which involves learning new concepts by solving practical cases.
- Improve the communication skills of students, thus allowing them to present an adequate demonstration and defense of their works.

This paper is aimed at evaluating the results of the workshops conducted during the summers of 2014, 2015, and 2016 in order for faculties from other institutions to benefit from the strategies used and adapt them to other disciplines. Moreover, the observed results could motivate teachers of other colleges to use tools such as construction toys, which are not usually used by high school or university teachers, to improve the learning experience of their students.

This paper is structured as follows. First, the selection process of the used construction kit is documented. Experiences with alternative sets are also documented. The scope of the proposed project and its main activities are then discussed. Next, the results of the project are reviewed; this section includes a detailed analysis of two analyzed proposals based on different approaches, a summary of the solutions proposed to simulate the different elements of the bridges (deck, pylon, arch, and cables), and the construction process. The results of a survey of the students are also presented. Finally, a set of conclusions is drawn and presented.

Construction System

Selection of the System

In the last decade, professors have become increasingly interested in developing more innovative and efficient teaching methodologies. In the structural engineering field, many scholars (Ji and Bell 2008) have suggested the incorporation of simple physical models and practical examples in these methodologies to aid students in developing an intuitive understanding of structural concepts, as well as to rouse their interest and curiosity. A number of construction sets have been presented in the literature for educational applications. Examples of the most common educational construction sets include (1) Lego, (2) Lupo, (3) Meccano, (4) Pasco [Fig. 1(b)], (5) K’NEX [Fig. 1(a)], and (6) Geomac.

A comparison of the main characteristics of each of the six analyzed construction sets is presented in Table 1 in terms of (1) element type, (2) connection type, (3) requirement of auxiliary

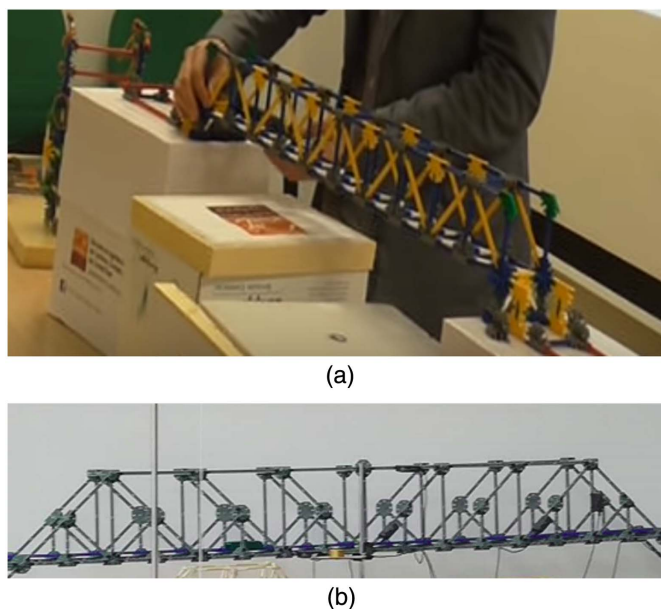


Fig. 1. Examples of construction kits: (a) K’NEX; and (b) Pasco. (Images by authors.)

Table 1. Comparison of characteristics of construction sets

Construction set	Element type	Connector type	Auxiliary elements	Average cost	Length of the longest element (mm)	Easiness of assembly	Main strength
Lego	Plastic blocks	—	No	€0.04	33	100	Widespread use and specific software: Robolab
Lupo	Building blocks of different materials	Binding wedges	No	€3.00	250	100	Large blocks
Meccano	Metal elements	Nuts and screws	Yes	€0.17	300	60	Widespread use and stiffness
Pasco	Plastic beams	Connectors and screws	Yes	€0.21	240	60	Sensors and devices specifically developed
K'NEX	Plastic rods	Plastic connectors	No	€0.05	86	100	Easy assembly
Geomag	Magnetic rods and bars	Steel spheres	No	€0.20	27	90	Magnetic connections

elements, (4) average cost per piece (averaged from the analysis of several kits), (5) length of the longest element, (6) assembly ratio (ranging from 0 to 100 based on the authors' personal experience), (7) easiness of assembly, and (8) main strength.

An analysis of the characteristics summarized in Table 1 indicates that the systems that present the easiest assembly method, and therefore reduce the construction time, include Lego, K'NEX, and Lupo. Among these three systems, the one that provides the greatest degrees of freedom for the design of geometries is K'NEX. Although Pasco also allows the construction of geometries suitable for the study of structures, the main difference between these two systems is their assemblage, construction speed, and auxiliary elements. The Pasco set requires auxiliary elements (bolts) at the connection between the bars and connector. The use of these elements slows down the assemblage process. In contrast, the K'NEX set consists of a unique type of lateral snap-in connection that speeds up the assemblage process. Unfortunately, this connection system is inconvenient in that it produces flexible connections because some rotation is always obtained between the bars at the connection.

Romero and Museros (2002) studied the stiffness of these connections as well as the strength of the K'NEX bars via laboratory tests. The main advantage of Pasco over K'NEX is the easy incorporation of custom sensors. However, the authors opine that this characteristic does not justify the high cost of this construction set. In addition, the structural response of the small-scale models developed using any construction set can be easily monitored with the low-cost technology proposed in the literature [such as Arduino (Chacon et al. 2018) or image-recognition techniques]. In addition, in practice, it is much easier to buy the K'NEX system than the Pasco system because no auxiliary bolts are required. Therefore, K'NEX was selected as the construction set for this work.

Use of K'NEX in Education

The K'NEX construction system has been extensively used during the last 2 decades as an innovative educational tool in a number of fields. For example, Ressler (1998) used K'NEX as part of a role-playing exercise to evaluate the importance of details in the success of projects. Burtner and Relyea (1998) used K'NEX in summer camps to stimulate interest in engineering in middle school students. Romero and Museros (2000, 2002) used small-scale K'NEX models and computer simulations to improve first-year high school students' learning experience of structural analysis and design. Blust and Bates (2004) used the K'NEX system to introduce students to lean concepts in a production management methods course. Considine and Lewis (2007) used the K'NEX system to introduce freshmen students to construction scheduling. Tims et al.

(2008) used the K'NEX construction set to introduce high school students to the structural response of bridges.

Welch (2009) used construction systems (such as Lego and K'NEX) to enhance students' creativity and capture their attention in a fun and tactile manner. Kunberger et al. (2010) used the K'NEX set to introduce students to engineering mechanics. Estes and Baltimore (2014) used K'NEX to illustrate the entire design-construction sequence of large structures to architecture students. Bennewitz et al. (2016) used K'NEX to develop students' problem-solving skills and creativity through the analysis of bone bioscaffolds. Estes and Baltimore (2014) used K'NEX to study the dynamic response of small-scale buildings.

In addition, K'NEX has been widely used in a number of design and construction students' competitions worldwide. Examples of these competitions include the Seismic Outreach Project at the University of California, San Diego (UCSD 2020), the Bridge Building Competition of Memphis University (NJSJBC 2020), the K'NEX challenge organized by Engineers Ireland (Newsgroup 2020), and the bridge design contest organized by the authors and promoted by the Civil Engineering School of the University of Castilla-La Mancha (UCLM 2020b).

Methodology and Organization of the Workshop

The activity was organized for the summers of 2014, 2015, and 2016. Four workshops were organized every summer. Each workshop was 1 week long and consisted of three parts. First, students received some lectures on the basics of bridge construction; when those were understood by the students, they were made to design and construct a bridge. Finally, the students shared what they learned by presenting their bridges to their partners. These phases of the workshop are detailed in the following paragraphs.

Phase 1: Understanding Bridge Behavior

The students were lectured on various topics during the first 3 days. These lectures covered a variety of topics related to the design and construction of bridges from an interdisciplinary viewpoint.

Lecture 1: Structural Mechanisms

Structural mechanics concepts were explained to the students in order to enable them to understand the working of the structures. In addition, basic properties of materials commonly used in civil engineering, as well as their applications, were explained. In order to capture their attention and curiosity, it was useful to analyze structures that were familiar to them. In addition, simple structural models were used to help them understand the structural mechanisms involved. Subsequent to the theoretical part of the lecture, they were introduced to the K'NEX Real Bridge Building kit,

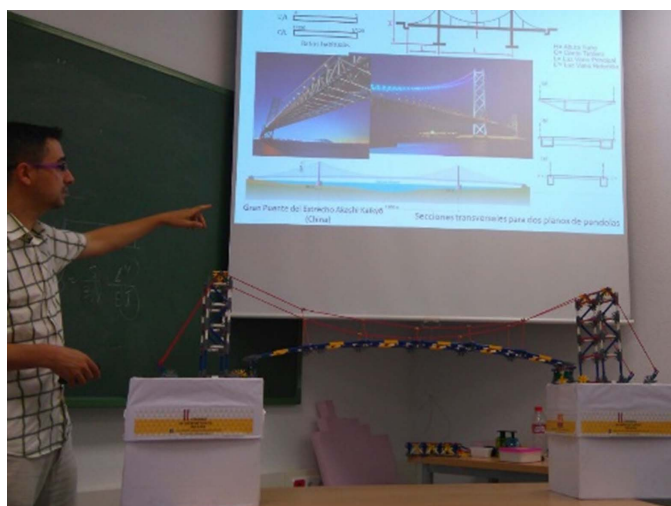


Fig. 2. Suspension bridges working explanation by pictures and a bridge mockup. (Image by authors.)

which they were made to use to construct a model of their own structure. This helped the students to understand important concepts such as load transfer.

Lecture 2: Typology of Bridges

In this lecture, various bridge typologies (beam, arch, truss, suspension, cantilever, and cable-stayed) as well as their functions were explained (Fig. 2). The use of the K'NEX kit as well as audiovisual materials helped the students to understand the various bridge typologies. In this case, the students could participate in the class development because they were encouraged to understand the bridges' functions in an instinctive manner by manipulating the K'NEX models.

Lecture 3: Site Visits

As part of this lecture, students were taken to Toledo to visit bridges of different typologies (Fig. 3). The authors could easily indicate the different parts of the bridge, how they work, and which factors affect the bridge stability, such that students could easily reinforce everything they had learnt in the previous lecture.

This lecture is interactive because the students can participate in it by sharing what they had understood in the previous lectures.



Fig. 3. Bellavista Bridge, Toledo, Spain. (Image by authors.)



Fig. 4. Students during the workshop on Arduino. (Image by authors.)

In addition, they could be inspired by their own bridge design and understand their bridge design in the context of its hypothetical location after visiting the actual location.

Lecture 4: Construction Process

In this case, the students learned a simplified version of the construction process of the different bridge typologies via audiovisual material regarding the construction of real bridges and K'NEX bridges, as well as via chronological diagrams of the process. This lecture constituted a guide for the students that indicated the steps that they must follow to construct their bridge in an appropriate manner during the workshop conducted in Phase 2.

Lecture 5: Workshop on Arduino

This lecture was divided into two parts (Fig. 4). The first part discussed basic bridge-monitoring concepts and why they are important. In addition, students were introduced to programming using an open-source electronic prototyping platform, Arduino. Second, the students were instructed to develop their own code to monitor their bridges using the Arduino platform.

Phase 2: Workshop on Bridge Design and Construction

In this phase, PBL was applied as a methodology for learning. The students were distributed into groups of 3–4 people for the workshop. They spent an entire day developing a project, which consisted of the design and construction of their own bridges, which were based on the knowledge they obtained in the previous phase.

First, they developed some bridge design ideas and discussed them in order to select the most suitable option. They then constructed the K'NEX bridge model (Fig. 5). They were provided with a set of pieces, and they built the model as a simulation of a real bridge-construction process. They took photographs during the process to show their partners at Phase 3. In this phase, the dimensions (span, arch rise, deck thickness, and arch thickness) and ratios (arch rise to span and deck to thickness span) of this structure were compared with those of similar arch bridges in the extant literature.

Phase 3: Presentation

Finally, in this phase, students prepared a 20-min presentation to summarize the results of the workshop. This presentation was divided in two parts. In the first part, they discussed the most



Fig. 5. Students during the construction process. (Image by authors.)

important aspects of the knowledge they had obtained during the previous phases. In the second part, they presented their bridge. This presentation included the following information: (1) description of the structural mechanisms of the different elements of their design, (2) description of the aesthetics of the bridge with respect to its surroundings, (3) description of the design process including the final dimensions and geometrical ratios as well as a comparison with similar structures in the extant literature, and (4) explanation of the construction process including a stop-in motion video of the staggered erection process.

When all the groups had made their presentations, the students were commissioned to discuss their bridge projects, as shown in Fig. 6.

It is important to highlight that the objective of the course is to introduce students (in a simplified and comprehensible manner) to the multidisciplinary design and construction of real bridge projects. In this context, the K'NEX construction set is only used as an educational tool that enables students to experiment with structural typologies and understand the technical contents of the course based on hands-on experience. As is apparent, the proposed methodology can be easily applied to other concepts and disciplines.



Fig. 6. Students during their presentations. (Image by authors.)

Observations and Results

This section presents the application of the PBL methodology to a specific group of students and a specific typology (arch) of bridges. This was applied along with the experience-based knowledge that has contributed to improving the results of the project.

Application of the Methodology

In every workshop, each group was instructed to build, according to their preferences, one of the main typologies of long-span bridges (arch, cable-stayed, or suspension). As an example, the results of the activity consisting of the design of one of these typologies, i.e., an arch bridge, is summarized in Fig. 7.

In this case, a trip to Toledo, Spain, was made to visit and observe different real-world bridges and the Peraleda Bridge, an arch bridge, in particular [Fig. 7(a)]. There, the students refreshed in their minds of the concepts that they had learned in class, identified the main forces acting on the different elements of this structure (arch, deck, and stays), and understood the important role of the ratios of the structural elements of actual bridges. With this aim in mind, the students were encouraged to draw sketches by hand during the visit and to review the proportions of the built arch bridges using the internet. This information they obtained allowed them to outline their first designs in drawings. A trial-and-error process was used to update these designs and to correct the geometrical limitations of the K'NEX construction system.

During the construction sessions [Fig. 7(b)], owing to the limitations of the K'NEX system, the structure was not built according to its actual construction process because the verification of the completed structure was an initial requisite. Therefore, the bridge was first built in one stage to verify its geometry. Then, its geometry was completely defined, and the bridge was disassembled and reassembled according to its actual construction process. At the beginning of this process, the deck segments were successively erected on temporary supports that transferred the load to the terrain (Phase 2.1). Then, the arch was built from both abutments using a cantilever method (Phase 2.2). Finally, once the arch was closed, the load from the temporary supports was transferred to the arch via the prestressing of a system of cables. After prestressing these elements, the final structure corresponded with that presented in Phase 2.3. Fig. 7(c) presents the proportions of the bridge in the drafts used by students during the presentation in Phase 3.

During the three summers of the project, a total of 46 different bridges were designed and constructed by the students under the supervision of the faculty team (12 arches, 12 cable-stayed, and 12 suspension bridges). During Phase 2 (bridge design and construction), the students prepared sketches of their designs and took photographs of both the design and construction processes. Moreover, they were encouraged to produce a time lapse video to simulate the bridge construction process (cable-stayed bridge, suspension bridge, and arch bridge). The participation in the presented project gave the authors a real and satisfactory complete picture of how successful the project had been. In addition, this material provided the authors with an opportunity to improve how they used K'NEX to teach bridge design and construction, which is explained in the following section.

Lessons Learned over the Years

Building K'NEX bridges is not as straightforward a task as it may appear. Finding the right combination of rods and connectors to mimic either a certain structural element or an adequate connection is a time-consuming process. Thus, over the years, with the help of students, professors have learned how to represent an increasing

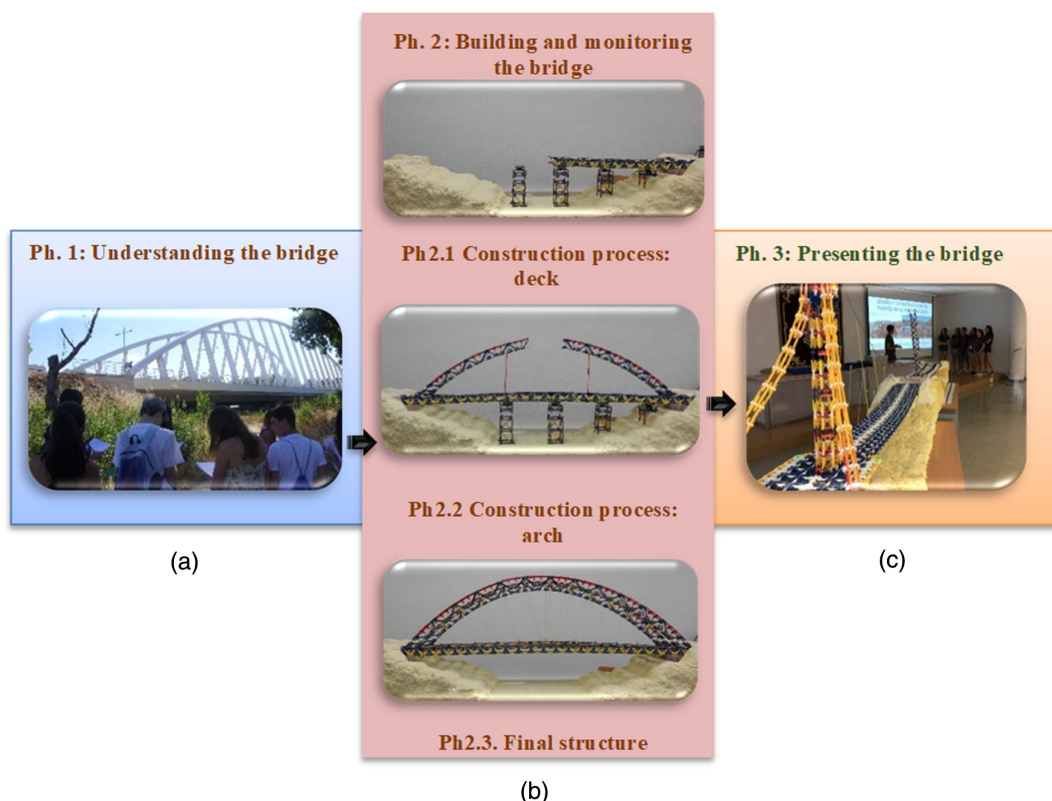


Fig. 7. Application of the methodology to design an arch bridge with K'nex: (a) students understanding the bridge behavior; (b) construction sessions; and (c) students presenting the resulting bridge. (Images by authors.)

number of details using this construction system. The learning process over the 3 years of the project (2014, 2015, and 2016) is summarized and illustrated for arch bridges in Fig. 8, which includes the selection of the built structures along with pictures of their most representative details in terms of decks and arches. As can be observed, the major differences among the projects are based on whether the students attended a class on the actual design of specific elements of the bridge, and they are encouraged to use these geometries in their proposals while ensuring that they are compatible with the K'NEX limitations. This consideration improves the bridge design significantly over time.

Three examples of arch-typology proposals with two planes of hangers are shown in Fig. 8. The first of these structures [Fig. 8(a)] comprises a flexible deck suspended from a stiff arch. It is based on the Sydney Bridge in Australia. Nevertheless, the lack of continuity of the bottom chord of the proposed deck made the design unrealistic.

Furthermore, the key element in an arch is its shape, but fabricating an adequate arch shape using K'NEX is challenging. Firstly, the shape of the bridge required significant improvement because it was far from the desired antifunicular shape, and secondly, the connection between the arch and abutment was inadequate because the arch section was inappropriately reduced at the proximities of the abutment.

In order to solve these problems, the lectures now explicitly include concepts of cross-section design (including ratios and proportions), funicular and antifunicular concepts, and the mechanism for properly transferring the horizontal loads of the arch to the terrain [Fig. 8(b)] or to the deck [Fig. 8(c)].

Some of the improvements realized (in terms of arch shape, the foundations, or the design of the deck cross section) can be illustrated in the bridge of Fig. 8(b). It is a skew arch to the line of the deck based on the Hulmen Bridge. Although this structure might be

appreciated from an architectural viewpoint, the deck weight introduces significant torsional loads in the arch. The lack of torsional stiffness of the arch resulted in increased deformations of the structure over time. One month after its construction, the geometry of the structure was too deformed to facilitate its actual use. This highlights the requirement of choosing between allowing students to select the design of their bridge (although it would be structurally deficient) and guiding them such that the selected solution is optimal.

Finally, the structure in Fig. 8(c) comprises a bowstring with two parallel arches similar to that of the River Usk Crossing in Newport (South Wales, UK). In this case, because the vertical stiffness of the arch is adequate and the torsional loads are limited, the structure works really well.

In addition to the arch, significant improvements were made in the detailing. A clear example of this is the hanger connections of the first structure [Fig. 8(a)]. This detail was unrealistic because the connections were made with simple knots. To solve this problem, auxiliary electrical material brackets were used as anchorages [Figs. 8(b and c)] not only for the arch bridge but also for the cable-stayed and suspension bridges. Besides, the shape of these pieces recall the dampers found in real structures.

Student Satisfaction Survey

In order to evaluate the students' appreciation for the proposed workshop, a survey was conducted during the third edition of the proposed workshop. The questions (Q) of this survey are listed in Table 2.

The 15 students that participated in the survey were requested to respond to these questions using ratings from 1 (minimum satisfaction) to 10 (maximum satisfaction). A summary of the survey results is presented in Fig. 9, wherein the satisfaction with respect to each question is categorized into three levels: (1) low satisfaction:



Fig. 8. Arch bridges showing details of the arches, decks, stay cables, and reference bridges. (Images by authors.)

rated lower than 5; (2) medium satisfaction: rated between 5 and 7; and (3) high satisfaction: rated higher than 7.

The analysis of Fig. 9 shows that the course has aroused in the students an interest in civil engineering (Q1). Moreover, 80% of the students reported a high level of satisfaction. Furthermore, the results showed that the course was well structured (93% of the responses to Q2 indicate a high level of satisfaction), and the practical classes were useful in helping the students to successfully solve the proposed tasks (80% and 100% of the responses to Q3 and Q4, respectively, reflected a high satisfaction). In addition, the score given by the students to the course was very high (100% of

responses to Q5 reflected a high satisfaction). Moreover, all the students reported that they would recommend this course to other classmates (100% of the responses to Q6 reflected a high satisfaction). From the responses to Q7, it could be concluded that more than 87% of the students would choose civil engineering as their degree in the next future. Only 13% of the students reported that they would not select civil engineering as a career. These results

Table 2. Survey conducted to the students

Id	Question
Q1	Has the course aroused your interest in Civil Engineering?
Q2	Is the course well structured?
Q3	Have the theoretical classes served to successfully carry out the tasks proposed in the workshops?
Q4	Have the practical classes and visits made in the course served to successfully carry out the tasks proposed in the workshops?
Q5	What score would you give this course?
Q6	Would you recommend this course to other classmates?
Q7	From this course, would you choose Civil Engineering as a degree to take in the coming years?

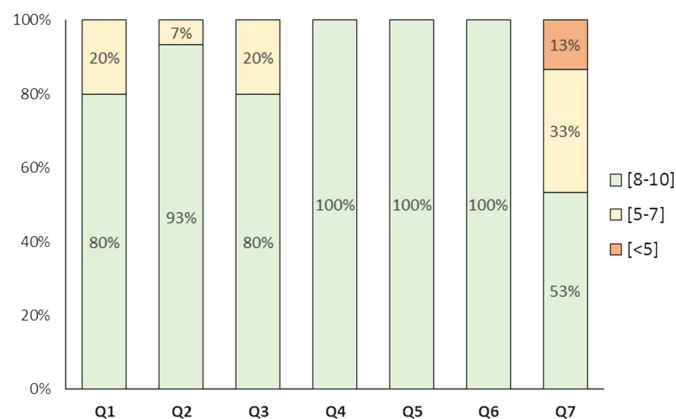


Fig. 9. Results of the satisfaction of the students in the survey.

showed the utility of the proposed workshop in encouraging prospective students to study civil engineering.

Conclusions and Ongoing Work

The objective of the presented workshop on bridge construction from a multidisciplinary viewpoint was successfully realized, as demonstrated by its popularity, and high participation among the students. The successive editions of the workshop have facilitated improvements in the design and construction strategies and the adaptation of K'NEX toy's limitations to the main objective. As has been demonstrated on an annual basis, the students and instructors were able to evolve in terms of designing more efficient construction details while approaching the actual behavior of structural elements in real-world bridges. Based on this knowledge, new projects are being proposed and executed during the year. A bridge construction contest using K'NEX for high school students (titled *Bridges to the Future*) has been organized annually (from 2015 to 2019) based on the results of the workshops. In this case, students are provided with a construction set, and they are required to complete the challenge over 4 weeks (Phase 2) in their own schools while being assisted by their teachers. Some students of the workshop in previous editions joined the activity and encouraged others to enroll as well. Lectures corresponding to Phase 1 were condensed in a master class, and the experiences from the previous years were recorded and made available for the ongoing contest, as given by UCLM (2020a). In Phase 3, students are organized in semifinals and challenged to build in teams a K'NEX bridge. The different proposals are evaluated with the following criteria: bridge span, cost of construction, aesthetical quality, structural typology, and maximum load-bearing capacity before collapsing. Finally, in Phase 4 the winners of the different semifinals participate into the contests' final, where they must adapt their bridges to a real environment with a fixed span of 2.0 m (UCLM 2020b) (Fig. 10).

In addition, a novel massive open online course (MOOC) for the multidisciplinary design of bridges was organized by the Civil Engineering School of the University of Castilla-La Mancha. Based on the experience obtained during the workshops, connectors and rods were modeled using the software Blender 2.78 in order to create virtual models to make understanding the explanations of technical concepts more enjoyable and easier.

In the first edition, 570 students were enrolled and 124 completed the course. Because Spanish is the language of instruction, 27% of the enrolled students were from Spain, 70% from Latin America, and only 3% from other countries.



Fig. 10. Presentation during the IV Grand Final, Plaza Mayor de Ciudad Real, June 2018. (Image by authors.)

As a limitation of this study, the authors do not have rigorous evidence of the realized student learning; however, it was observed that the majority of the high school teachers involved in the bridge-construction contest returned every year with new students to participate in the contest. Therefore, the authors found the basis and origin of these new experiences to be of significant interest and worth presenting herein. The authors are convinced and hope that the faculties of other institutions could benefit from the strategies presented herein and could adapt them to other disciplines or focus them on specific topics of civil engineering.

Data Availability Statement

No data, models, or code were generated or used during the study.

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