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Application of teaching-learning methodologies for the conceptual design of a Vertical Garden mobilization system using MMF

Aplicación de metodologías de enseñanza-aprendizaje para el diseño conceptual de un sistema de movilización de Huerto Vertical utilizando MMF

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Abstract

The project consisted of design and construction of a mechanical prototype that allows the growth of vegetables in a rotary vertical garden. For the vegetables to grow properly, the structure of the prototype rotates in order to provide them homogeneous sunlight. Currently, the movement of vertical structures is carried out with motors and mechanical transmission systems; however, in this case it was to carry it out with shape memory materials (SMMs), which could rotate the system with the application of electric current, hot air or sunlight. During the development of the prototype, it was possible to use previously designed equipment where experiments can be carried out to characterize the behaviour of the SMMs, applying different voltages to them. This work shows the methodology used to involve students, from two institutions, in the design stages, taking advantage of experimental tests, digital resources on the internet; as well as the application of active methodologies such as project-based learning and flipped classroom. Finally, a proposal is presented for the remote operation of the equipment used in the characterization of the materials and their use as learning technics.

Engineering education, Project Based Learning, Flipped Classroom

Resumen

El caso de estudio consistió en el diseño y construcción de un prototipo mecánico que permita el crecimiento de hortalizas en un huerto vertical. Para que las hortalizas tengan un apropiado crecimiento, la estructura del prototipo gira con la finalidad de otorgarles luz solar de manera homogénea. Actualmente el movimiento en estructuras verticales es realizado con motores y sistemas de transmisión mecánicos; sin embargo, en este caso se propuso llevarlo a cabo con materiales con memoria de forma (MMF), los cuales podrían hacen girar el sistema con la aplicación de corriente eléctrica, aire caliente o luz solar. Durante el desarrollo del prototipo fue posible utilizar equipos previamente diseñados donde se pueden realizar experimentos para caracterizar el comportamiento de los MMF, aplicándoles diferentes voltajes. En el presente trabajo se muestra la metodología usada para involucrar a los estudiantes, de dos instituciones, en las etapas del diseño, aprovechando la realización de pruebas experimentales, recursos digitales en internet; así como la aplicación de metodologías activas como el aprendizaje basado en proyectos y aula invertida. Finalmente se presenta una propuesta para la operación a distancia de los equipos utilizados en la caracterización de los materiales y su utilización como elementos de aprendizaje.

Enseñanza en la ingeniería, Aprendizaje basado en proyectos, Aula invertida

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Introduction

In Mexico as in the world, agriculture has for centuries been an essential part of societies, providing them mainly with food and livestock (Matarin, Urrestarazu, & García, 2014). One of the most important parts of modern agriculture is horticulture, which contributes to feeding families, helps maintain good nutritional levels and is also a means for farmers to gradually learn to adopt new technologies from the simple to the complex (Kozai & Niu, 2016).

Although since ancient times there are records of dissemination of knowledge to conserve and improve the practice of agriculture (Gómez & Luque, 2007), with the growth of population there are new problems to solve, such as considering that the space to cultivate and the distribution of agricultural products become more complex within large cities (Pérez, 2021) and (Banerjee, 2014). Authors such as Kalantari, Mohd, Akbari, & Fatemi, (2017), Cazorla (2021) and Chozo (2021) mention that in the next 50 years, 80% of the population will live in urban areas. This is why one of the options that has recently been considered is vertical farming, which allows considerable quantities of agricultural products to be grown in small spaces. However, this type of agriculture presents several complexities such as: water distribution, placement, geographical location, sun distribution on plants, among others (Kalantari, Mohd, Akbari, & Fatemi, 2017) and (Benke & Tomkins, 2017).

The above makes the proposed designs for this type of agriculture diverse (Soria, 2018) and (Banerjee, 2014), which is evident in a number of patents that attempt to solve such problems from a technical point of view (Patent No. US4295296A, 1981) and (Patent No. US9010022B2, 2011). The disadvantages of some vertical designs include inadequate light distribution for proper plant growth or harvesting. In order to solve this, rotating devices have been designed that allow sunlight to be evenly distributed on each plant (Benke & Tomkins, 2017) (Banerjee, 2014) and harvesting is easy. These devices are driven by means of motors, geared motors, mechanisms and control systems that can eventually be both complex and costly, especially when increasing light input (Kalantari, Mohd, Akbari, & Fatemi, 2017).

One option to realise the required turning movement in vertical seeding structures is through the use of shape memory materials (MMF) as they exhibit effects that conventional materials do not possess: single shape memory effect, superelastic and double shape memory effect (Otzuka & Wayman, 1998). Particularly the single shape memory effect can be used in this case because it consists of the recovery of apparently plastic deformations by increasing the temperature above the critical temperature of the material (Melton, 1998). These materials are called smart because one of their main advantages is that they function as sensors and actuators at the same time (Hassanien, Al-Emran, & Shaalan, 2020), which simplifies their implementation in devices that need to generate movement (Hassanien, Al-Emran, & Shaalan, 2020).

Considering the aspects mentioned above, a collaborative project was developed between two Mexican institutions to carry out the design and construction of a mechanical prototype that allows the growth of vegetables in a vertical structure powered by MMF. The project was financed with federal and state resources after participation in a national call for proposals where the feasibility of the project was evaluated. During its implementation, teaching and learning methodologies were applied (project-based learning and inverted classroom), as well as experimental tests and digital resources on the internet, so that the participating students could learn the necessary theoretical aspects involved in the problems presented for the mobilisation of the vertical garden and thus have a more active participation in all stages of the project.

This work shows some stages of both the mechanical design and the construction of the proposed prototype, with the aim of highlighting the results obtained by the participating students and identifying a series of methodological steps that can be used as a strategy for teaching-learning, at undergraduate level, when developing short-term application projects. Finally, an additional proposal for the remote operation of the equipment used in the characterisation of the MMFs is described, which will be integrated into the general methodology used in this case study, in order to be applied in future projects between the two institutions.

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Methodology

Researchers, professors, graduates and undergraduate students of Industrial Engineering and Mechanical Engineering, belonging to the Tecnológico de Estudios Superiores de Chalco and the Applied Mechanics Laboratory of the Centro Tecnológico Aragón, FES Aragón UNAM, respectively, participated in the project. The methodology, results and discussion presented in this work are only focused on the teaching aspects in order for the undergraduate students who participated in the project to acquire new knowledge and contribute as much as possible to the development of the project.

Teaching and learning methodologies

Project-based learning was used in this case because it is an educational methodology based on the philosophical need for a purpose in the teaching-learning processes and because its current formulations identify this purpose with the existence of an external objective (for example, in this case, building the prototype) that is used as a context for instrumentalising the learning of both models and scientific procedures, giving rise to scenarios in which students self-manage and plan to varying degrees (Domenech-Casal, 2017). For its part, the flipped classroom pedagogical model was used because it consists of inverting certain learning processes that previously took place in the classroom, transferring them outside the classroom, i.e., carrying them out at home, and vice versa (González & Abad, 2020). Additionally, it was used because this teaching methodology involves students reading, visualising, reflecting on and understanding the content prepared by the teacher, and then resolving any doubts and problems that arise in the classroom (González & Abad, 2020).

Student activities during the development of the project

The activities for the students were divided into three main parts:

1. Identification of techniques and processes used for growing vegetables both conventionally and vertically.

Due to the fact that the students participating in this project are trained with a profile that is not related to the subject of agriculture and livestock, as mentioned by (Abella et. al., 2020), it was necessary to motivate them to become familiar with central themes related, in this case, to the production of vegetables and the development of urban gardens. Among the most important technical aspects they had to observe were those used for conventional vegetable growth and to identify the problems and adaptations that are required for the correct vertical growth of vegetables. The aim was that, when proposing and designing vertical prototypes for vegetable cultivation, they would consider fundamental aspects in the cultivation, growth, maintenance and behaviour of a selected vegetable, as well as the technological options recently used. For this purpose, digital material was compiled on the planting process, specialised horticultural production manuals to identify parameters of plant growth and health, as well as the processes of plant adaptation to vertical systems. Some of these materials were observed in the classroom, others were left for consultation at home, applying inverted classroom strategies (González & Abad, 2020) and (Bishop & Verleger, 2014) so that their doubts were resolved in subsequent sessions. Some examples of the support materials used are (Jeavons, 1991), (PPD, 2016) and (Baixauli & Aguilar, 2002).

2. Identify the main aspects of mechanical design used in vertical structures

Once the students were involved in the application of technologies for food cultivation, emphasis was placed on the arrangements used in the design of conventional vertical systems by showing them various experiences of mobilised vertical cultivation. For this purpose, videos, digital theses and thematic manuals were used, which were explained to them in person and others as homework, guiding them to work on essential activities following the methodology proposed by (Abella et. al., 2020). Some examples of the support materials used are (Cazorla, 2021), (Chinchilla, 2020), (Valadez, 2014), (Soria, 2018), (Banerjee, 2014) and (Tendencias Tecnológicas, 2019).

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For the generation of design proposals adapted to regional conditions, challenges were posed (Abella et. al., 2020), such as the development of prototypes using recycled materials in their construction and manual mobilisation. Conceptual designs in CAD software and their scale construction were requested. Part of the bibliography provided to the students as support for the design of the mobilised vertical structure or vertical orchard are those reported by (ANelA, 2015), (Lawrence, 2014), (Benke & Tomkins, 2017) and (Herrera, 2020).

3. Movement of the structure using MMF

Since the mechanical behaviour of MMFs is highly anisotropic, temperature-dependent and hysteretic (García-Castillo, Cortés-Pérez, Amigó, Sánchez-Arévalo, & Lara-Rodríguez, 2015) (Taillard, Arbab-Chirani, Calloch, & Lexcellent, 2008) (Novák, Šittner, Vokoun, & N., 1999) and (Novák, Šittner, & Zárubová, 1997), it was necessary to provide students with a basic course on these materials. In this course, they were provided with a bibliography covering the theoretical aspects considered for the understanding and study of MMFs (Tobushi, Date, & K., 2010) (Jiujiang, Naigang, Huang, Liew, & Liu, 2002), (Melton, 1998) (Kumar, 2008); as well as on their use in various applications (Tobushi, Date, & K., 2010) (Zhuet. Al., 2001a) (Zhu et. al., 2001b) (Kaneko & Enomoto, 2011) (Melton, 1998). It should be noted that the literature on these topics was divided and the studies and research that have been developed by the FES Aragon working group were shared separately. Some of these works include both theoretical aspects and applications (Castillo, 2016) (Cortés J., 2007) (Cortés R. , 2013) (Cortés U. R., 2018) (García-Castillo, Cortés-Pérez, Amigó, Sánchez-Arévalo, & Lara-Rodríguez, 2015) (González S. C., 2013) (González S. C., 2016) (Lizardi, 2018) (Riveros, 2015) (Taboada, 2016).

In addition, previously designed and built didactic equipment was used so that the students could have a better understanding of the behaviour of the materials and could carry out characterisation tests. Figure 1. a) shows a conventional spring (MMF)-spring series arrangement and how the shape memory spring contracts as the applied voltage increases. Figure 1. b) shows an analogous configuration, but with a wire (MMF)-conventional spring combination.

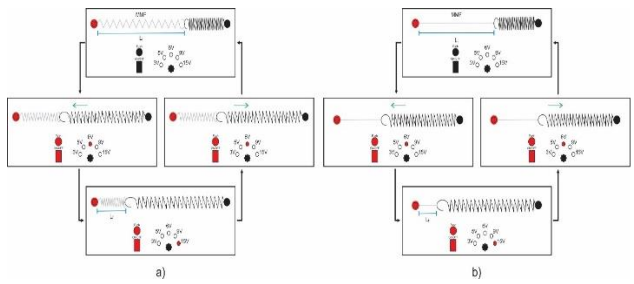

Figure 1 Arrangements used for the characterization of MMFs a) Spring-loaded b) Wire-loaded

Results

The results are focused on some of the activities carried out by the students during the development of the project, highlighting the conceptual design of the vertical structure and how to generate the rotational movement in it.

Design and construction of prototypes

The students proposed several structures after applying the methodology described in the previous section. Some of them were built with materials or elements that were available to them. The designs first made in CAD and then built can be divided into two main parts:

1. Prototypes without the use of MMF.

Prototype 1. Metal with bicycle parts

The proposed prototype consisted of a rectangular structure 31.5 in high by 17.71 in long and 12 in wide, built with 1 ½ in rectangular steel profile. It consisted of a proposed bicycle pulley as a transmission mechanism coupled to a chain with half-inch steel tube rungs joined by welding, which transported pots for planting. The mobilisation of the prototype was manual and they found both the need to hold the rungs carrying the pots at both ends and the independence of the rotation of the pots for the correct rotation. In figure 2 a) and b) you can see the prototype made in the CAD software while in figure 2 c) its construction.

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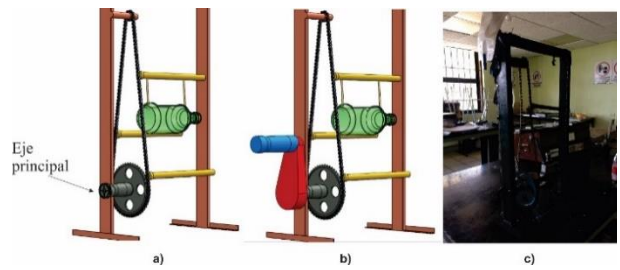

Figure 2 Prototype 1. a) In CAD indicating the main axis to generate the movement. b) In CAD with manual drive. c) Constructed

Prototype 2. Wooden with office chairs and PET bottle rings.

The proposed prototype consisted of a rectangular structure 70.86 in high by 24 in long and 4.59 in wide, built with 2 in x 1 in pine wood strips. In this proposal, reinforced crosspieces were placed at the bottom as a base for support, while for the rotating system, reused bases from discarded chairs and broomsticks were used as crosspieces to support hanging pots. Rings from bottle necks were placed on the crossbars to allow the bottles to rotate freely, thus immobilising their horizontal displacement. PET bottles from 2-litre soft drinks were used for the pots. Their movement was also manual. The prototype is obviously sensitive to humidity and of low resistance, so it was clear to the students (in this and in the other prototypes developed) that in the final design the materials used for its construction would have to be different.

In figure 3 a) and b) you can see the prototype made in CAD software while in figure 3 c) its construction.

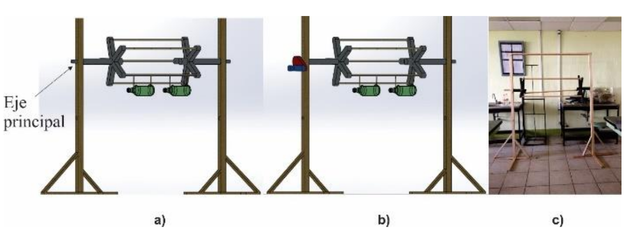

Figure 3 Prototype 2. Made of wood with office chairs and PET bottle rings. a) In CAD showing the main axis to generate the movement. b) In CAD with manual drive. c) Constructed

Prototype 3 Metal with bicycle wheels

This prototype has dimensions of 63 in high by wide, it was built with used bicycle wheels and half inch steel tubes. To support it, 1 ½ in x 1 ½ in steel angles were used and the movement was manual.

Like the previous prototype, PET bottles were used for the pots. In figure 4 a) you can see the prototype made in the CAD software while in figure 4 b) you can see the construction of this prototype.

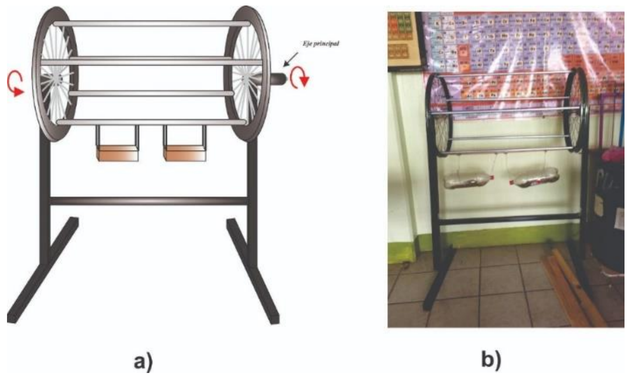

Figure 4 Prototype 3 Metallic with bicycle rims. a) In CAD indicating the main axis to generate the movement. b) Constructed

Prototype 4. MDF rail prototype

In this MDF prototype, the possibility of using a rail to direct the crossbars to transport the pots was considered. It has dimensions of 17.71" high by 17.71" long and 10" wide. In figure 5. a) you can see the prototype made in the CAD software while in figure 5. b.) you can see its construction.

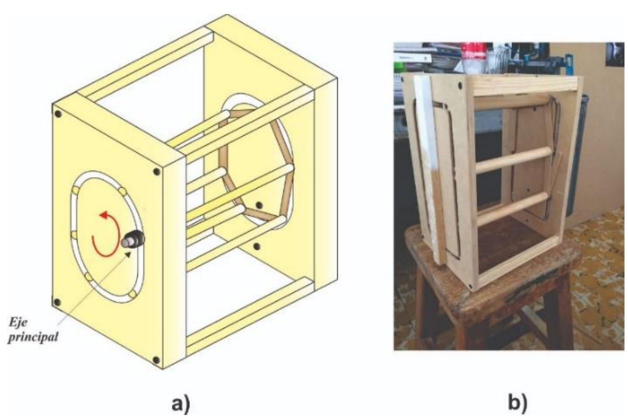

Figure 5 Prototype 4. MDF rail type prototype. a) In CAD indicating the main axis to generate the movement. b) Constructed

Prototype 5 Integration of experiences

Prototypes 1 to 4 allowed the students to integrate their experiences to solve technical problems and make decisions for the final design. The structure whose dimensions were 59 in high, 59 in long and 44 in wide was manufactured in 1 ½ in 14-gauge PTR and for the movement system a transmission shaft, catarinas, bearings and 40 pitch chain were used.

Figure 6. a) shows the prototype made in the CAD software while figure 6. b) shows its construction.

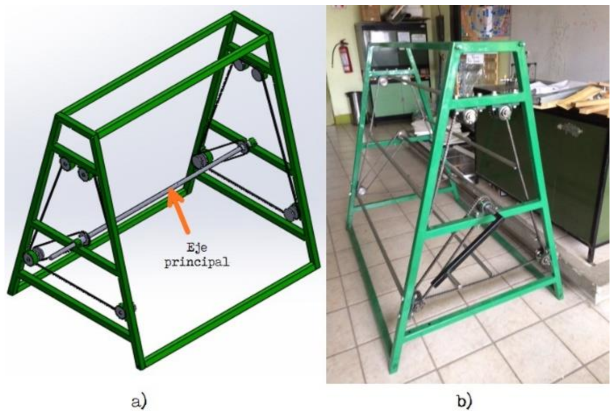

Figure 6 Prototype 5 Integration of the experiences. a) In CAD indicating the main axis to generate the movement. b) Constructed

Movement with motors and placement of pots for vegetable cultivation.

As can be seen in figures 2 to 6, each prototype has a main axis in its design to place a handle or attach any type of mechanism that fulfils the function of achieving the rotating movement. The prototype "Integration of the experiences", shown in figure 6, was fitted with a 60 Hertz single-phase alternating current motor with its geared motor.

In all the prototypes, the pots are placed on the crossbars for planting vegetables. In prototypes 2 and 3, PET bottles with a capacity of 3 litres were used as pots for growing vegetables, these were hung using bottle necks to achieve their independence by turning the crossbars and rope. For prototype 5, bottle necks were also used to hang the pots, but these were made of recycled high density polyethylene with dimensions 7.87 in x 6.2 in x 23.62 in, inside each pot, a mixture composed of 40 parts by 10 parts of coconut fibre and compost was used as planting substrate.

2. Prototypes using MMF

For the project, Ni-Ti wires and springs were purchased to carry out characterisation tests using the arrangements shown in figure 1. This characterisation was used to calculate the weight that each design could lift. Figure 7 shows the 5 prototypes with proposals to obtain the rotary movement of the structure, where the integration of some devices using MMF can be appreciated.

The arrangement in figure 7 a) does not perform a complete rotation since it consists of 4 cantilever beams; however, it is possible to take advantage of the rotation in only one direction. As far as the configuration in figure 7 b) and c) is concerned, they have the same working principle, except that in the first one the rotation of both pulleys is used. For the next arrangement, figure 7 d), a crank-crank-slide mechanism is proposed where the displacement generated by the contraction and stretching of the MMF is used. Finally, for the last arrangement, the coupling of a heat engine is considered, which works with hot and cold water. As it can be noticed, only the system that does not allow the complete rotation in a continuous way is the one integrated in the prototype 1.

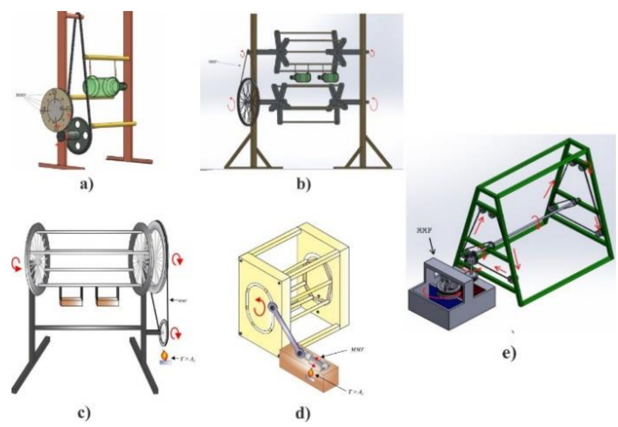

Figure 7 Prototypes with motion using MMF

Discussion

The design proposals made by the students show that they assimilated the knowledge that was transmitted to them during the realisation of the project. Despite the good results obtained by the students, some important aspects found regarding their performance and the methodology used should be noted.

- Active methodologies and short-term application projects

It was evident from the beginning of the project the need to use active methodologies for students to learn better. This is because they have been widely used for years with students at all school levels. However, these methodologies are often not used individually.

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For example, in the inverted classroom, despite having advantages such as: allowing the teacher to give a more individualised treatment covering all phases of the learning cycle (Vidal, et. al., 2016), allowing the student to obtain information in a time and place that does not require the physical presence of the teacher; as well as organising the order of their learning, they are not sufficient in our case study. The main reason for this is that in the case of higher education, the learning methodologies used should focus on the student learning through the application of knowledge in real cases. That is why project-based learning was used, which has some advantages such as: developing skills aimed at solving a problem that is part of reality, independent work, use of ICT, among others (Marti et. al., 2010) and (Vidal, et. al., 2016). In the project developed, some of these advantages mentioned in both methodologies were noticed when looking at the performance of the students, where new competences were shown (Shuhailo & Derkach, 2021). Despite this, it should be considered that, although the methodology (ABP) has been applied for the last 40 years in engineering education because it has presented good results (Chen, Kolmos, & Du, 2021), it is sometimes focused on being applied in courses that are only contemplated in the curricula (Sandoval et. al., 2021), (Mingorance et al., 2017). Even the success cases reported are with the use of projects that have already been completed, i.e. when the problem has been solved (Abella et. al., 2020). Cases such as the one shown in this paper tend not to be used as a teaching course because they are funded projects, due to be delivered in the short term and clearly not within a specific subject. In the case of this type of project, the active methodologies considered relevant can be used, but other aspects must undoubtedly be taken into account. This example and others show the current need to develop hybrid learning methodologies (Azevedo & Morales, 2021). In addition to the above, sometimes there is no culture of pedagogical training in these projects due to the pressure generated by the delivery of these projects and similar situations that the teacher or researcher does not encounter in regular courses.

- Expertise, permanence and time of the students within the working group.

As previously specified, the project required the use of MMFs which have a complex thermo-mechanical behaviour. Topics such as mechanical anisotropy, hysteretic behaviour, non-linear mathematical models, among others had to be explained in a different way considering the time to complete the project. In general, funded projects require previous evaluations to be approved and this often leads to proposing topics that are beyond the scope of knowledge of the undergraduate students. In this case this problem was less of a problem because the students involved had been in the working group for a considerable time and helped those who had not.

- Multidisciplinary working group

The project involved the participation of researchers, professors and graduates from the participating institutions working in engineering areas such as industrial, mechanical, electrical and electromechanical engineering. Having a multidisciplinary group allowed the students the possibility of having more support alternatives to clarify their doubts.

Remote handling of equipment

The points mentioned above were discussed from the beginning by the responsible group of both institutions by comparing them with the experience they have had in terms of application projects and university-industry linkage projects. However, one of the additional disadvantages encountered was that the two universities involved were at a considerable distance from each other. This led to communication problems, especially between students at different universities. A similar problem occurred with the characterisation of the MMFs due to the fact that the equipment used for this purpose is located in one of the participating institutions. It is for this reason that this activity was mainly carried out by students who were close to the equipment. This aspect can generate a major problem in the students' knowledge assimilation because it is well known that the development of laboratory practices in the different specialties plays an important role in complementing the objectives and contents of the Educational Teaching Process (Mar et. al., 2016).

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In fact, in general, due to various factors, each higher education institution has different teaching resources which are available according to its trajectory and research development, which limits the comprehensive learning of some students.

For this reason it is important to establish a plan that allows the use of the resources of both universities without the need to move. In this sense, the evolution of technology has contributed to the development of various areas of society, with distance education being one of its main beneficiaries (Andújar & T.J., 2010). Even more so in these times of pandemic, distance education has become the only option for continuing education at all levels of education around the world. In fact, nowadays, alternatives have been created such as simulators or remote laboratories, which can be accessed from anywhere with the use of the internet, presenting advantages over traditional ones because they invite enquiry in a safe and economical way (Martínez, 2021). Remote laboratories allow real systems to be operated and controlled remotely by means of an experimental interface running on a computer connected to a network, known as a telelaboratory, remote laboratory or web-based teleoperation. However, although the advantages that these laboratories facilitate are evident, as of 2016, only 5% of universities and research centres in the world that offer distance learning courses incorporate these types of laboratories in their study programmes (Mar et. al., 2016).

Thanks

The experience described was developed within the framework of the project, Application of materials with shape memory, for the movement of horizontal vegetables made of recycled material, which benefited from the Convocatoria de Apoyo a la Investigación Científica y Tecnológica 2017, issued by Tecnológico Nacional de México.

Explicit thanks are extended to the students involved, the working group of the Applied Mechanics Laboratory of the Aragon Technology Centre at FES Aragon and students of Industrial Engineering of the Tecnológico de Estudios Superiores de Chalco, TESCHA.

As part of the collaboration between the two institutions, the intention is to integrate the use of remote teaching equipment in future projects, which could help interaction between students from both institutions to be more dynamic, as it will allow students who are far away to use the equipment. Figure 8 shows schematically the connection that would be used.

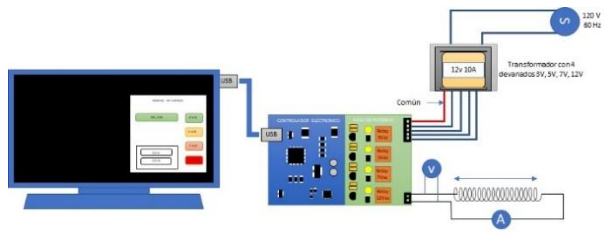

Figure 8 Scheme for the use of remote teaching equipment

Conclusions

The students participating in the project were able to propose conceptual designs of prototype structures for vertical planting of vegetables and their mobilisation using MMF. This was possible because during the development of the project a series of steps were carried out in order to make the students' learning as fast as possible and thus to have their participation more active. The methodological steps reported in this work focused only on aspects of teaching and learning of the students. Because this type of projects are short-term and funded (TecNM, Convocatoria de Apoyo a la Investigación Científica y Tecnológica 2017, Profesores con SNI y Perfil PRODEP) they have very specific characteristics that require more teaching resources than the active methodologies applied can provide. Given the exchange conditions, the methodology used can be improved in future projects by incorporating the manipulation of teaching equipment remotely.

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