BOARD # 176: Building Light, Thinking Bright: Engaging Secondary School Students in Lightweight Design

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Building Light, Thinking Bright: Engaging Secondary School Students in Lightweight Design

Abstract – This paper describes a state-funded initiative aimed at introducing fundamental concepts of lightweight design to young individuals through interactive workshops conducted at universities and industrial facilities.

The primary focus of the workshops taking place at our university is to demonstrate the varying deflections of cantilever beams with different cross-sections but identical weights under loading conditions. Additionally, they shall highlight how the natural frequencies of bending vibrations are influenced by the area moments of inertia of the beams.

The elaboration of the teaching content and method as well as the design of a suitable experimental arrangement was entrusted to a team of three graduate students in their first year of an automotive engineering master's degree program. Their aim was to introduce children between the ages of 8 and 14 to some essential aspects of lightweight design by means of static and dynamic experiments with cantilever beams in an age-appropriate way.

For this purpose, standard profiles were selected that have approximately the same mass per unit length, but different flexural rigidities due to different materials and shapes of their cross-sections. The aim is to demonstrate that different profiles can influences the load capacity of a structure without necessarily changing its weight. These profiles are clamped on one side and loaded by a point load at the free end for the static experiments. Due to the different bending stiffnesses, different deflections are achieved with the different profiles, even though they weigh the same. To convince the participating audience, these beams should be easily removable for weight comparison.

Another topic of the planned workshops is the deliberate shift of the natural frequencies of a structure through a suitable selection of the profiles to avoid undesirable resonances while maintaining the weight of the structure. This is demonstrated by carrying out modal analyses with the same cantilever beams as for the static tests. The experiments are performed live in front of the audience using accelerometers, an impact hammer, and a data acquisition system. As a result, the natural frequencies and vibration modes of the cantilevers are obtained and visualized on a computer screen. In addition, two-dimensional vibrations are also demonstrated in order to vividly visualize oscillation modes in the form of Chladni patterns.

In addition to conceptualizing the experiments, the project team designed a tailor-made laboratory trolley on which all experiments can be carried out. Thus, the experimental setup is also suitable for use in other contexts, such as lectures in mechanics and strength of materials.

This paper describes the design of the experiments, the development of the experimental setup and experiences from first experiments.

Introduction

As we navigate through the ever-evolving educational landscape, the integration of interdisciplinary and hands-on learning experiences is increasingly recognized as crucial, not just for those with a predisposition towards engineering disciplines, but for all students. This paper deals with an aspect of a state-funded project designed to introduce the principles of lightweight design to pupils at elementary, middle and high school level. Lightweight design is an intriguing field focusing on developing materials and structures that are both light and strong, which is crucial in industries like aerospace, automotive, and renewable energy (see, e.g., [1, 2]).

The significance of lightweight design extends beyond its technical applications; it embodies a philosophy of maximizing efficiency and innovation, which are valuable skills in any field.

The rationale for targeting students of this age group, particularly those who may not yet be inclined towards a technical education, is twofold. First, early exposure to complex concepts helps demystify science and engineering, potentially sparking interest in STEM subjects (science, technology, engineering and mathematics). Second, the skills developed through understanding and applying the principles of lightweight design – such as analytical thinking, problem-solving, and creativity – are universally applicable and crucial in a wide array of academic and career paths. These competencies help prepare students to navigate and adapt to the rapidly changing demands of the workforce.

To ensure the effectiveness of this educational endeavor, the project is structured around a series of hands-on workshops. These workshops are designed to be engaging and informative, allowing participants to explore the principles of lightweight design through interactive and practical experiences. A critical aspect of the project's success lies in its collaborative framework, which mandates partnerships between industry and educational institutions as a prerequisite for funding. This collaboration ensures that the workshops are grounded in real-world applications and that the content delivered is both current and relevant.

In alignment with the overarching goals, our institute has specifically set out to emphasize the critical role that the cross-sectional properties of structural elements play in determining their load-bearing capacities. Understanding these principles is fundamental to the field of lightweight design, where the optimization of structural components often hinges on the careful consideration of geometry. To effectively convey this concept to young participants, we have developed a series of hands-on demonstrations focused on cantilever beams – an ideal example of how cross-sectional properties influence structural performance.

The workshops feature, amongst others, practical experiments with cantilever beams that are identical in both weight and length but differ in their flexural rigidity. Variations in cross-sectional geometry directly affect the beams' ability to resist bending when subjected to a static load. By clamping these cantilevers and applying the same load to each, participants can observe varying degrees of deflection. As the participants witness the differing performances of beams that, at first glance, appear to be quite similar, they will gain a deeper appreciation for the importance of design in engineering. By directly engaging with these physical demonstrations, the young participants are likely to develop a more intuitive understanding of how structural elements are designed for strength and efficiency, which is a key learning outcome of the workshops.

In addition to illustrating the impact of the beam cross-section geometry on the load-bearing capacity of cantilever beams, we are also committed to demonstrating the relationship between these properties and the natural frequencies of structural elements. The area moment of inertia, a key factor in determining a beam's stiffness, also plays a crucial role in influencing its natural frequency. Beams with higher moments of inertia, which are stiffer and less prone to bending, generally have higher natural frequencies. Conversely, beams with lower moments of inertia tend to have lower natural frequencies due to their increased flexibility. By carefully selecting the cross-sectional geometry to adjust the moment of inertia, engineers can strategically shift the natural frequencies of structural elements away from potential excitation frequencies, thereby minimizing the risk of resonance – a phenomenon that can lead to catastrophic failure if not properly managed.

This aspect of the workshops is intended to provide the young participants with a holistic understanding of how the design of structural elements involves balancing multiple factors, including strength, stiffness, and dynamic behavior. By exploring the interplay between these variables, they will gain insight into how engineers optimize designs to ensure both structural integrity and dynamic stability.

To ensure that the workshops are both educational and engaging for the young participants, we entrusted the task of planning the experiments and designing the experimental setup to a team of three highly motivated students from our master’s degree program in Automotive Engineering. These students, at that time in their first year of study, have already acquired a solid foundation in the principles of lightweight design, making them ideally suited for this project. Their fresh perspective and strong grasp of the subject matter enabled them to create a learning experience that is both accessible and impactful for the target age group.

The student team was responsible for conceptualizing the experiments that are used to demonstrate key principles such as the effect of cross-sectional properties on load-bearing capacity and natural frequencies. Their role included designing and constructing the physical setups required for these experiments, ensuring that they are not only technically sound but also easy to understand for the younger audience.

This paper outlines the design of the experiments, the development process of the experimental setup and first experiences with demonstrations in front of school classes and visitors to the *Long Night of Research* (in German “Lange Nacht der Forschung”) – a nation-wide event in Austria promoting science, research and innovation that is aimed at all age groups.

Design of the Experiments

In the course of the first project meetings of the student team with their supervisors, a test arrangement emerged in broad strokes, which essentially includes three topics: static deflection, vibration behavior, and its visualization in an easily comprehensible form. The use of cantilever beams for the static bending tests was obvious, as deflections that are easily visible to the naked eye can only be achieved with beams with a free end. The weight placed on the free end of the cantilever beam should also be not too large to minimize the risk of injury in experiments in the presence of children (Figure 1).

Lightweight design does not only include the static load-bearing capacity; due to the applications in aeronautical and automotive engineering and many other disciplines, the dynamic properties of a structure also play an essential role. These properties are essentially shaped by the natural frequencies and oscillation modes of the structures. The relationship between excitation frequencies and natural frequencies plays a decisive role here. A structure must be designed in such a way that its natural frequencies do not lie in the range of the excitation frequencies as far as possible.

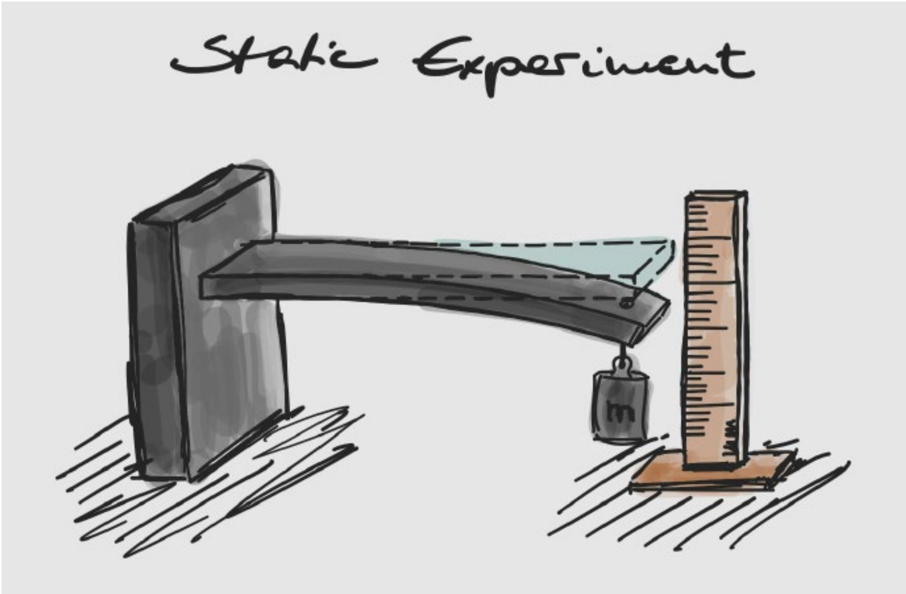


Figure 1: Freehand sketch for the bending test on the cantilever

The natural frequencies of beams depend on their lengths and bending stiffnesses, which can also be demonstrated in experiments. The easiest way to do this is by means of modal analysis. Modal analysis is the numerical or experimental characterization of a dynamic system by the modal parameters natural frequency and damping as well as associated natural vibration forms [3]. In experimental modal analysis, these oscillations can be excited by an impact hammer and recorded by several sensors, usually accelerometers (see Figure 2).

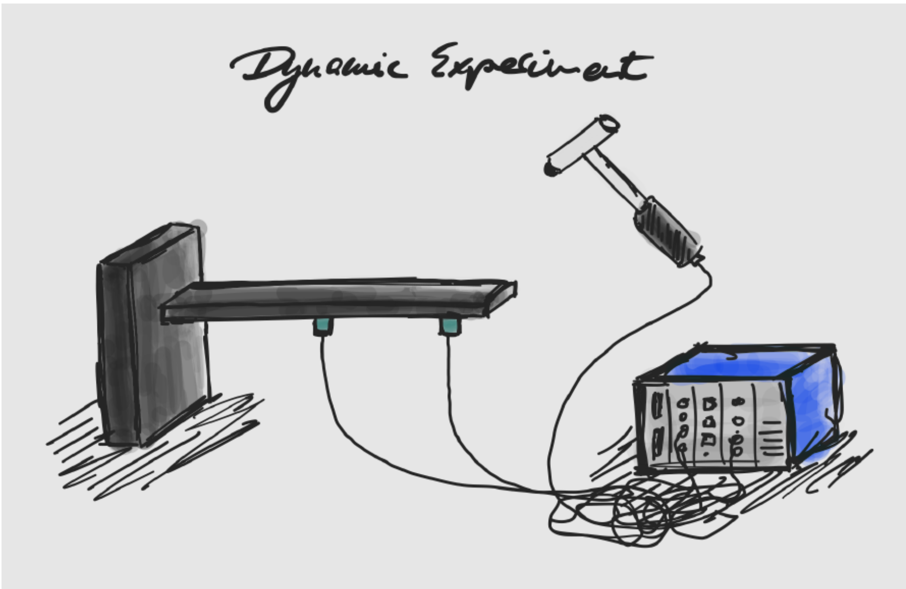


Figure 2: Freehand sketch for the impact test on the cantilever

It is apparent that a decisive factor for the design of the experimental arrangement is the dimensioning of the cantilevers, so that both static and dynamic experiments with effects recognizable to the participants of the workshops are possible. Since the length of the cantilevers is limited to less than one meter due to the requirement that the experimental arrangement should be portable, sufficient deflection of the cantilevers must be achieved by correspondingly low bending stiffnesses.

Bending Line of a Cantilever Beam

A cantilever beam subjected to a point load at its free end provides a classic problem in the study of beam deflection and stress distribution. Consider a cantilever beam of length L, with a constant flexural rigidity EI (where E is the modulus of elasticity, and I is the area moment of inertia of the cross-section). The beam is fixed at one end ($x = 0$) and free at the other end ($x = L$). A point load P is applied at the free end (cf. Fig. 1). The bending moment $M(x)$ at a distance x from the fixed end due to the point load at the free end can be expressed as

$$M(x) = -P(L - x) \tag{1}$$

According to the Euler-Bernoulli beam theory (see, e.g. [4]), the relationship between the bending moment and the beam deflection $z(x)$ is given by

$$EI\,\frac{\mathrm{d}^2 z(x)}{\mathrm{d}x^2} = -P(L - x) \tag{2}$$

By integrating the moment-curvature equation (2) twice and applying the boundary conditions $z(0) = 0$ and $z'(0) = 0$, the equation of the deflection line

$$z(x) = -\frac{P}{6EI}\left(3Lx^2 - x^3\right) \tag{3}$$

is obtained. Hence, the magnitude of deflection at the free end of the beam due to the point load P is given by $z(L) = PL^3/3EI$. The length of the beam enters into the deflection with the third power and thus has the greatest influence; the flexural rigidity has an inversely proportional effect. Figure 3 shows the deflection lines of two 470 mm long and equally heavy cantilevers with different cross-sections (rectangular and T-shaped), both of which are loaded with a point load of 50 N at the free end. Both profiles are made of non-alloy structural steel S235JR, with the rectangular profile having 45 x 5 mm and the T-profile having 30 x 30 mm with a wall thickness of 4 mm, i.e. both have the same cross-section and thus the same mass of 1.77 kg per linear meter.

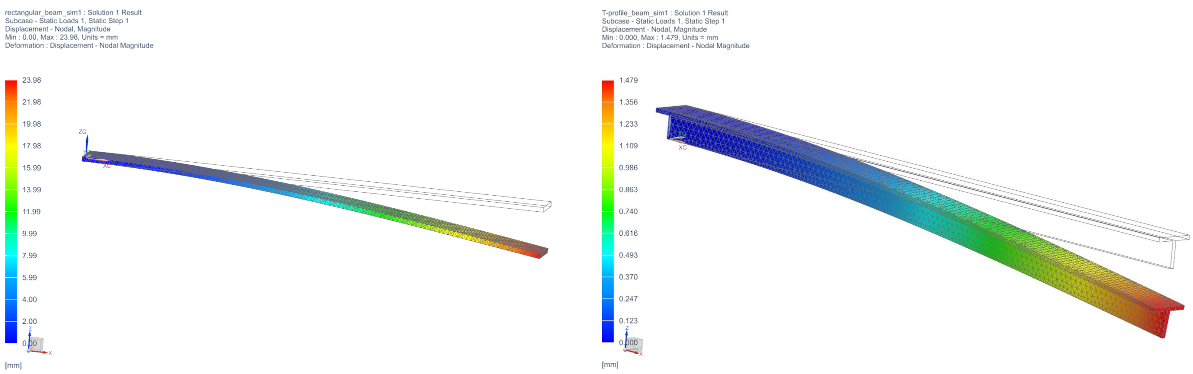


Figure 3: Deflections of rectangular and T-shaped cantilever beams with point load on tip

The maximum deflection of the rectangular beam is about 18 mm, while that of the T-shaped beam is less than 1 mm. That's a big enough difference to easily see the effect with the naked eye.

Bending Vibrations of a Beam

The Euler-Bernoulli beam theory also provides a foundation for analyzing the bending vibrations of beams. This theory is particularly applicable to slender beams where the length is significantly greater than the cross-sectional dimensions and the beam material is linearly elastic, homogeneous, and isotropic.

The transverse displacement $z(x,t)$ of a point on the beam at position x and time t can be described by the Euler-Bernoulli beam equation for free vibrations

$$EI\frac{\partial^4 z(x,t)}{\partial x^4} + \rho A\frac{\partial^2 z(x,t)}{\partial t^2} = 0. \tag{5}$$

The flexural stiffness EI, the density ρ, and the cross-section A are assumed to be constant over the entire length of the beam.

A separation-of-variables approach of the form $z(x,t) = X(x)T(t)$, substituted in equation (5), yields after rearrangement

$$c^2\frac{1}{X(x)}\frac{\mathrm{d}^4 X(x)}{\mathrm{d}x^4} = -\frac{1}{T(t)}\frac{\mathrm{d}^2 T(t)}{\mathrm{d}t^2} = \omega^2, \tag{6}$$

with $c = \sqrt{\frac{EI}{\rho A}}$. The temporal equation has a solution of the form

$$T(t) = C_1\cos(\omega t) + C_2\sin(\omega t) \tag{7}$$

where the constants C_1 and C_2 will eventually be determined by the initial conditions after being combined with the spatial solution (see equation 11).

By defining $\beta^4 = \frac{\omega^2}{c^2}$ so that $\omega = \beta^2\sqrt{\frac{EI}{\rho A}}$, a solution to the spatial equation can be written as

$$X(x) = A_1\cos(\beta x) + A_2\sin(\beta x) + A_3\cosh(\beta x) + A_4\sinh(\beta x)\,. \tag{8}$$

Values for β and three of the four constants of integration A_1, A_2, A_3, and A_4 can be determined from the four boundary conditions $X(0) = 0$, $X'(0) = 0$, $X''(L) = 0$, and $X'''(L) = 0$. These four conditions yield equations in the four unknown constants of integration, which can be written as a single matrix equation. A nontrivial solution for the vector $\mathbf{A} = (A_1, A_2, A_3, A_4)^T$ exists only if the determinant of the coefficient matrix equals zero, which yields the characteristic equation

$$\cos(\beta L)\cosh(\beta L) = -1. \tag{9}$$

This equation is satisfied for an infinite number of choices for β, denoted β_n. These solutions to the characteristic equation (9) determine the natural frequencies of the cantilever beam by $f_n = \frac{\beta_n^2}{2\pi}\sqrt{\frac{EI}{\rho A}}$ (and $\omega_n = 2\pi f_n$). The natural frequencies increase with the square root of the flexural rigidity. Beams with higher moments of inertia, like the T-shaped beam, exhibit higher natural frequencies compared to beams with lower moments of inertia, such as the rectangular beam. Even with the same weight and length, the dynamic response of the beams varies significantly due to differences in their cross-sectional geometries.

The vibration modes are then given by

$$X_n(x) = D_n\left\{[\cosh(\beta_n x) - \cos(\beta_n x)] + \left[\frac{\sinh(\beta_n L) - \sin(\beta_n L)}{\cosh(\beta_n L) + \cos(\beta_n L)}\right][\sinh(\beta_n x) - \sin(\beta_n x)]\right\}, \tag{10}$$

where D_n denotes the arbitrary magnitudes of the eigenfunctions [3]. Finally, the solution to equation (5) for the transverse displacement $z(x,t)$ takes the form

$$z(x,t) = \sum_{n=1}^{\infty} (A_n \cos(\omega_n t) + B_n \sin(\omega_n t))\, X_n(x), \tag{11}$$

where A_n and B_n are determined by the initial conditions.

Both the natural frequencies f_n and the mode shapes $X_n(x)$ of a transversally oscillating beam are not explicitly dependent on time, and thus also independent of the initial conditions. Thus, they can be calculated without specified initial deflection. The weighted frequencies $\beta_n L$ for the first four natural vibration shapes of a cantilever beam (clamped-free boundary conditions, equation (9)) are 1.875, 4.694, 7.855, and 10.996, respectively [5, 6]. The first four bending mode shapes for the cantilever beam are shown in Figure 4.

The oscillation behavior of an excited structure is a superposition of the oscillation modes, whereby the weighting of each individual mode is determined by the specific type of excitation.

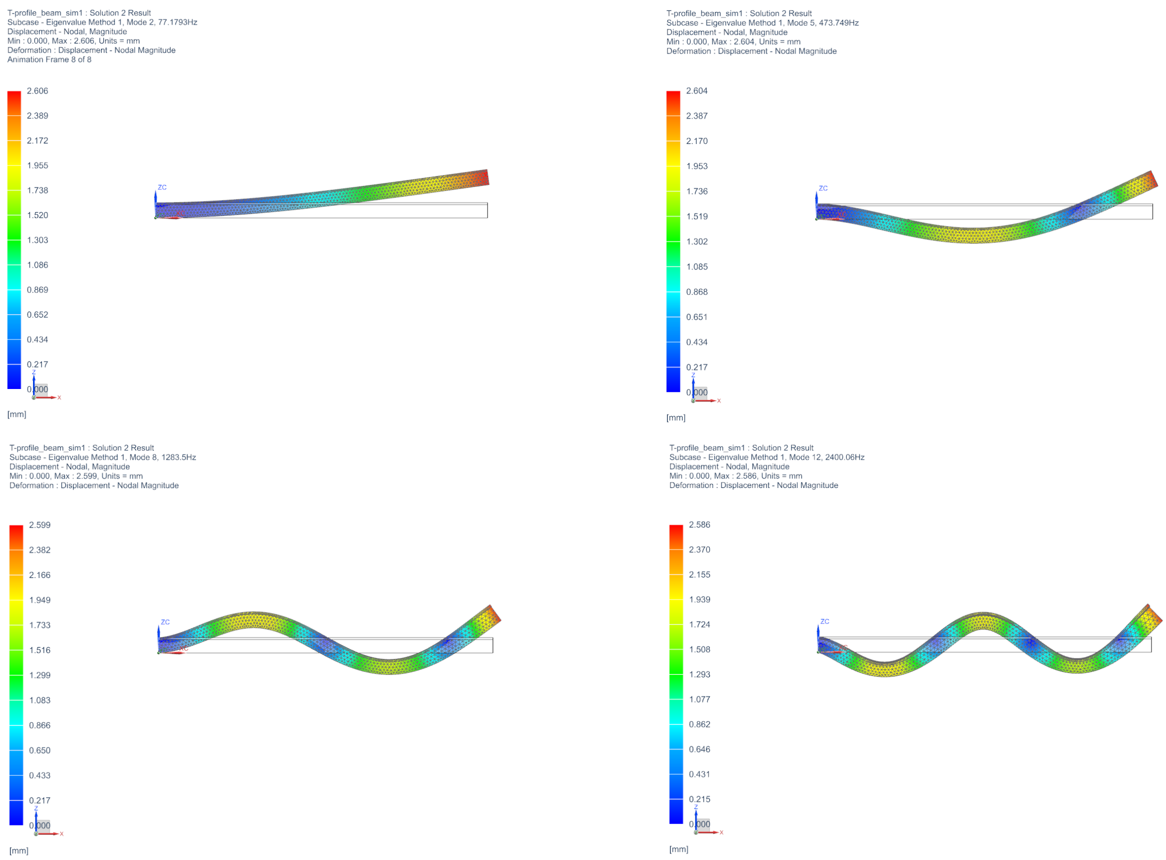
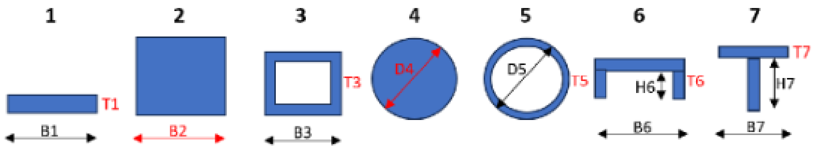


Figure 4: Bending modes of T-shaped cantilever beams (1st to 4th from top left to bottom right)

In order to find suitable beams that have approximately the same mass but significantly different bending stiffnesses, a MATLAB script was programmed based on the equations derived above that can be used to automatically calculate the maximum deflections and natural frequencies for different profiles. An excerpt of the MATLAB code is shown in Figure 5. The variable dimensions are indicated by the contours of the profiles displayed on the user interface and can therefore be easily varied.

Beam deflection and mode shapes

Definition of beam geometry:




```
geometry.n = [1,2,3,4,5,6,7]; % choose beam geometry (insert the number from the figure above (seperate with a comma))
material = 'steel'; % choose beam material ('steel', 'alu')

geometry.L = 0.470; % beam length in m

geometry.B1 = 0.02; % rectangular profile beam 1 width in m
geometry.B3 = 0.04; % square hollow profile beam 3 width in m
geometry.D5 = 0.05; % circular hollow profile beam 5 diameter in m
geometry.B6 = 0.04; % u-profile beam 6 width in m
geometry.H6 = 0.01; % u-profile beam 6 height in m
geometry.B7 = 0.02; % t-profile beam 7 width in m
geometry.H7 = 0.02; % t-profile beam 7 height in m
```

Definition of beam mass & load:

```
geometry.M = 0.295; % beam mass in kg
load.m = 0; % beam load in kg
```

Definition of number of beam mode shapes

```
mode.n = 5; % number of beam mode shapes
```

Figure 5: MATLAB script for the calculation of beam deflection and mode shapes

The actual bending oscillation behavior of a vibrating beam can be investigated by modal analysis. For this purpose, a force is applied at a point in the structure to be investigated, which can be done in the simplest case by means of an impact hammer (see Figure 2). An impact hammer has a force sensor on the striking side of the hammer head that measures the force as it strikes. At other points in the structure, the response signals are measured by means of accelerometers, and the respective transfer functions calculated. By determining the transfer function at a sufficient number of points in the structure, the natural frequencies f_n and mode shapes $X_n(x)$ can be determined. Commercially available data acquisition devices allow the calculation of these transmission functions and the representation of the frequency spectra. But there are also nice examples of self-compiled modal analyses in the context of student projects, which enable the visualization of the measured natural vibration shapes [7, 8].

However, more complex oscillation patterns are obtained when standing waves are generated on membranes. A simple but effective way to do this is to excite vibrations of a membrane-like two-dimensional structure, on the surface of which granular material, such as sand or salt, is distributed. Regions which have large amplitudes of oscillation, the antinodes, will shake the grains off and away, while regions with zero motion, i.e., the nodes, will collect the grains. The patterns that form in this way represent the individual vibrational modes, which are of course more complex than in the case of the one-dimensional beams (Figure 6).

This concept was invented by the German physicist and musician Ernst Florens Friedrich Chladni (1756-1827), one of the pioneers of experimental acoustics, and the figures created by the nodal lines on the vibrating plates are called Chladni patterns in his honor [9].

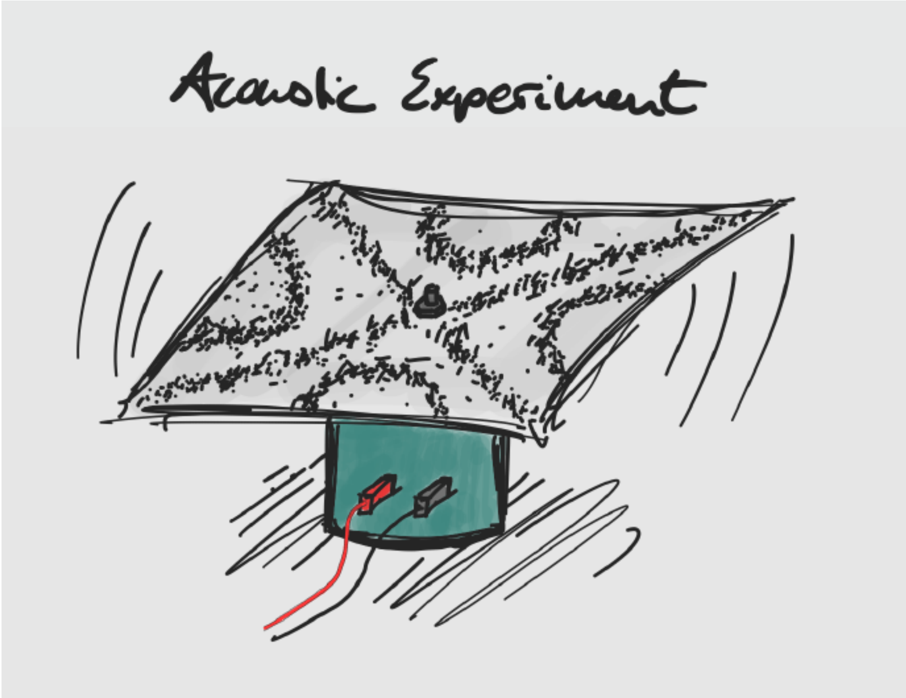


Figure 6: Freehand sketch of the Chladni plate experiment

In this experiment, with a suitable dimensioning, the respective resonance frequencies can be acoustically perceived as tones of different heights, and at the same time the associated natural oscillation modes can be observed.

In this way, three different experiments emerged, which together are intended to bring about the desired learning effect. Now it was necessary to develop a suitable experimental setup on which all three experiments could be carried out.

Development of the Experimental Setup

Taking into account the physical principles described above and the need to make the experimental arrangement portable and small enough to be able to get through doors, ideas for implementation were gathered and depicted in a sketch (Figure 7).

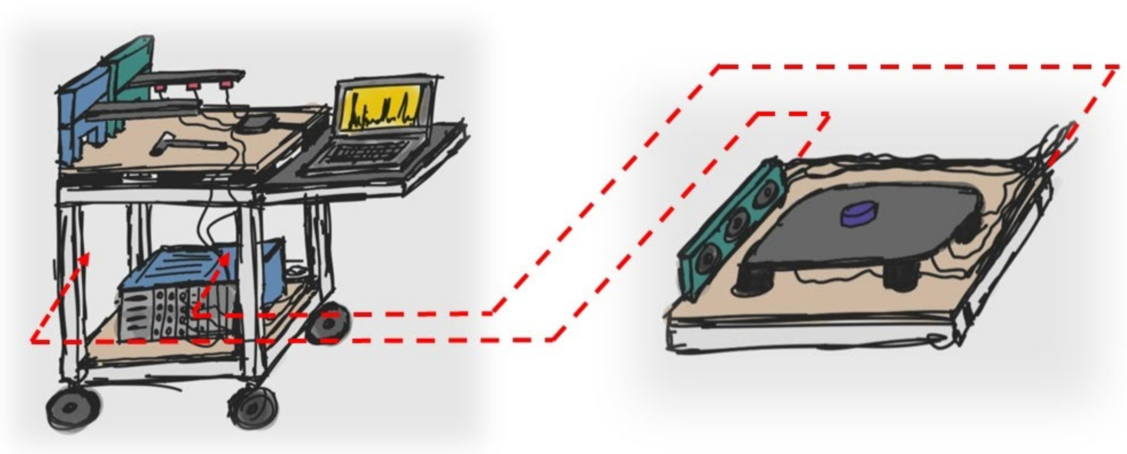


Figure 7: Freehand sketch of a mobile experimental setup

In order to have more space when experimenting, an additional foldable worktop was planned. The experiments are to take place on the upper deck of the arrangement, while the data acquisition hardware is housed in a more protected area on the lower deck. The acoustic experiment for the Chladni patterns is to be accommodated in the trolley but can be set up separately for the experiments.

Figure 8 shows the final version of the trolley. It is the result of several iterations to build a fully functional trolley as cost-effectively as possible.

Figure 8: 3D CAD model of the trolley; left in open position, right in transport mode

The next step was the development of the attachment of the cantilevers to the test setup. To a certain extent, contradictory requirements must be met. On the one hand, the clamping should be as stiff as possible to meet the boundary conditions for the bending line and the bending oscillations. On the other hand, however, the elastic coupling between the different profiles should be as low as possible in order not to distort the natural frequencies. In addition, the profiles should be able to be quickly installed and removed again so that they can be given between experiments to the participants of the workshops for weight comparison.

Figure 9 shows an initial concept for clamping cantilevers of different profiles by means of quick-release fasteners. A rubber layer is inserted between the clamp brackets and the beams to dampen the transmission of vibration.

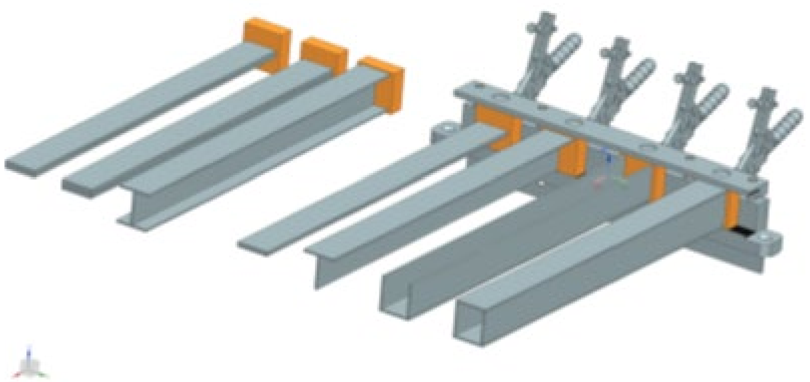


Figure 9: Clamping of the cantilevers by means of quick-release fasteners

As a second clamping concept, a separate bracket was provided for each cantilever, which achieves better decoupling from other parts. In the end, however, the decision was made to use a common bracket with star knobs for tightening (Figure 10).

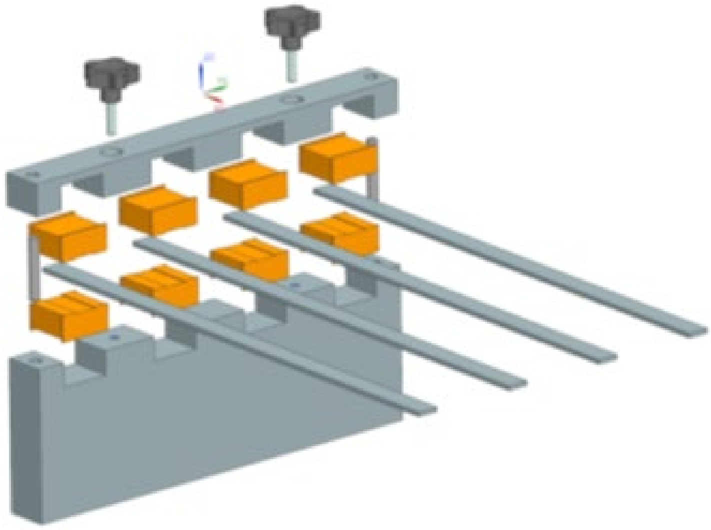


Figure 10: Clamping of the cantilevers by means of quick-release fasteners

The cantilever beams are held in place by machined or 3D-printed brackets that are adapted to the cross-sectional profile. The material is selected based on the results of reference impact tests (Figure 11).

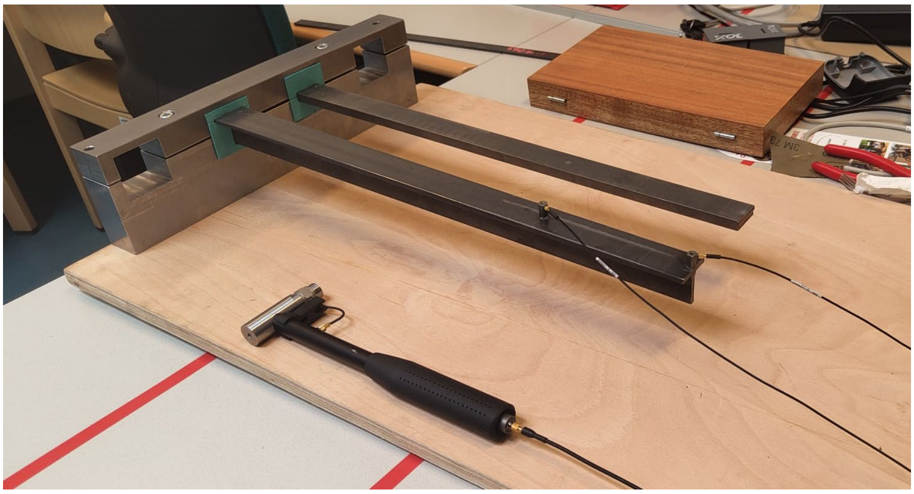


Figure 11: Provisional modal analysis for reference measurements.

The natural frequencies determined by the modal analysis can be displayed on the screen, but the natural vibration forms are not recognizable to the observer. For the young workshop participants to get a pictorial idea of such oscillation modes, another experiment was envisaged. Parallel to the impact hammer experiments, a thin metal plate or membrane is also to be stimulated to vibrate in such a way that the standing waves can be made visible to the naked eye.

The shape of the standing waves depends both on the boundary conditions, i.e. the clamping of the thin metal plate, and on the type of excitation. The clamping type determines the degrees of freedom of the test object, influencing the eigenfrequencies, mode shapes, and resulting patterns for the 2D visualization. The clamping type in Figure 12 represents fixed (Dirichlet) boundary conditions along the edges of the metal sheet. This fixation requires a strong excitation to create discernible Chladni patterns, as higher energy levels are needed to induce elastic deformation and was therefore discarded.

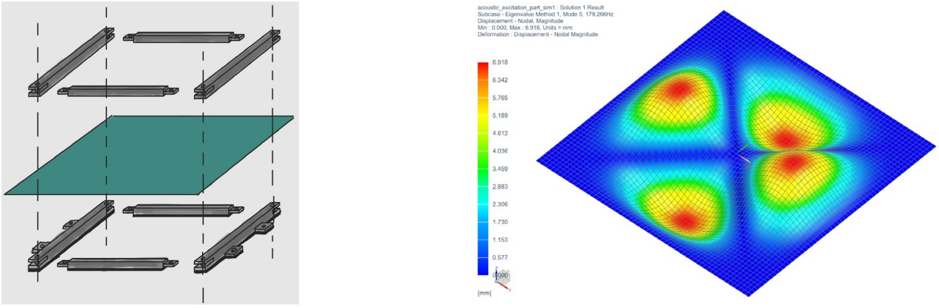


Figure 12: Thin metal sheet fully clamped along the edges (left), Siemens NX simulation (right)

The suspension in Figure 14 illustrates an almost freely supported metal sheet on rubber bands. This kind of support does not constrain any degree of freedom of the oscillations and requires much less intense excitation, which makes it suitable to an excitation via sound waves. The non-contact experimental setup utilizes a speaker capable of producing high air displacement (Figures 13 and 14). By generating a pure sine wave at a specific frequency, the oscillating motion of the speaker moves the air volume, causing the metal sheet to oscillate correspondingly.

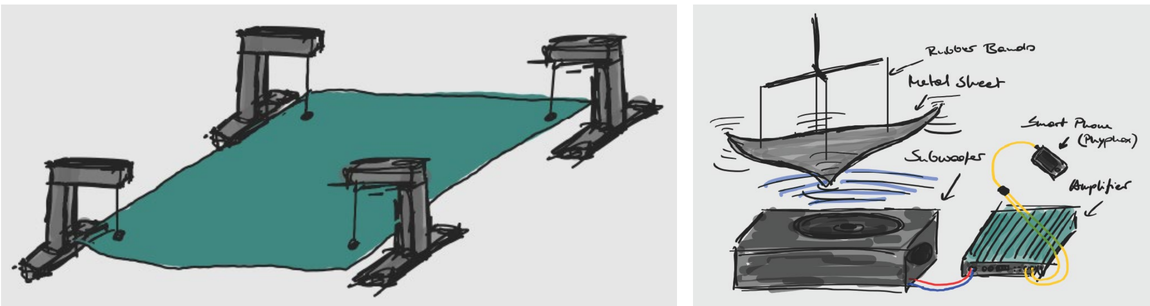


Figure 13: Thin metal sheet freely supported on rubber bands

The primary issue was aligning the sheet horizontally. Even small deviations significantly affected the behavior of the salt on the surface of the sheet. Despite numerous adjustments and variations in sound levels, visible Chladni patterns could not be achieved with this suspension (Figure 14).

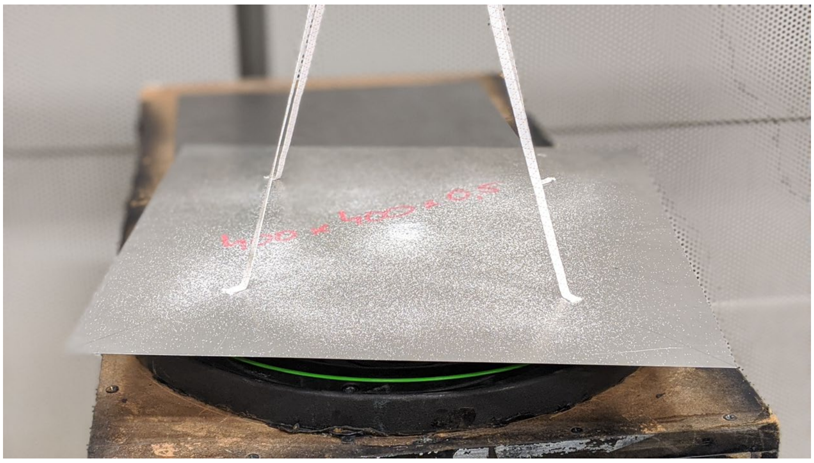


Figure 14: Non-contact excitation of an aluminum sheet using sound waves

In the experimental setup in Figure 16, the thin metal plate is connected to a vibration generator in its center via a rod. On the one hand, this rod serves as a support, and on the other hand, it directs the sinusoidal excitation through the vibration generator directly into the center of the plate, which should lead to standing waves as shown in the Siemens NX simulation of a higher-order vibration mode on the right-hand side of the figure.

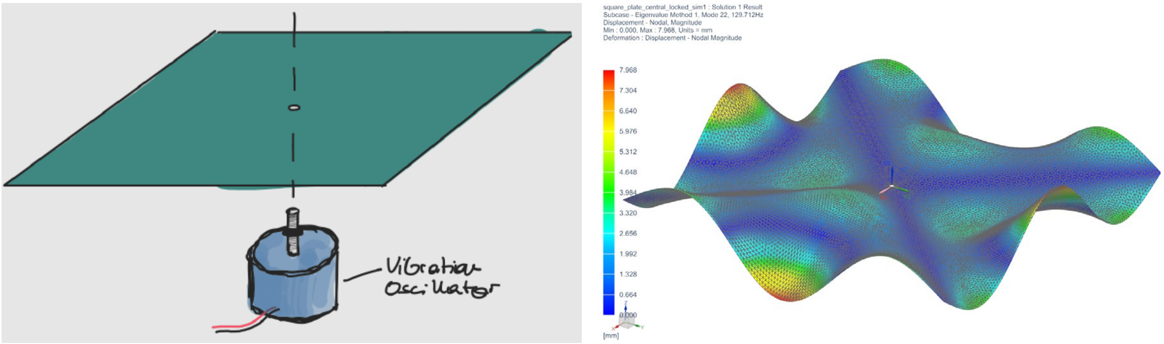


Figure 15: Thin metal sheet centrally clamped to a vibration oscillator

The entire experimental setup with the centrally supported and excited plate is shown in the hand sketch in Figure 16.

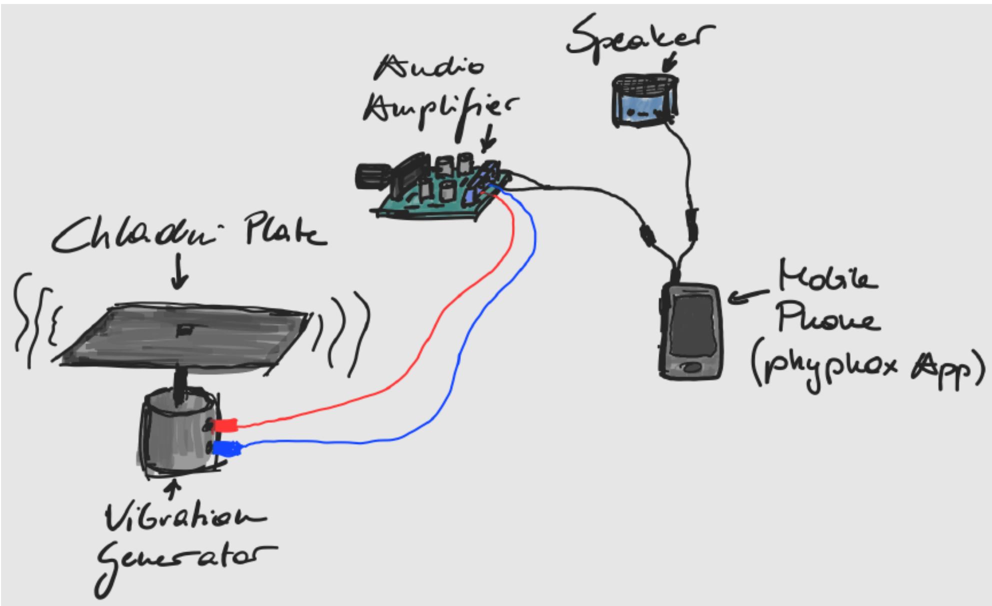


Figure 16: Using a smart phone with an amplifier to excite a centrally clamped metal sheet

A smartphone and the *phyphox* application are used to generate sinusoidal signals of different frequencies. The freely available app *phyphox* (an acronym for ***phy***sical ***pho***ne e***x***periments) has access to the sensors and actuators installed in the smartphone, can read or control them and contains mathematical algorithms for data analysis [10]. The sine wave signal generated by the app is transmitted to an amplifier via an auxiliary cable to increase the signal amplitude. A standard loudspeaker was used as a vibration generator, with the connecting rod glued to the middle of the diaphragm (Figure 17).

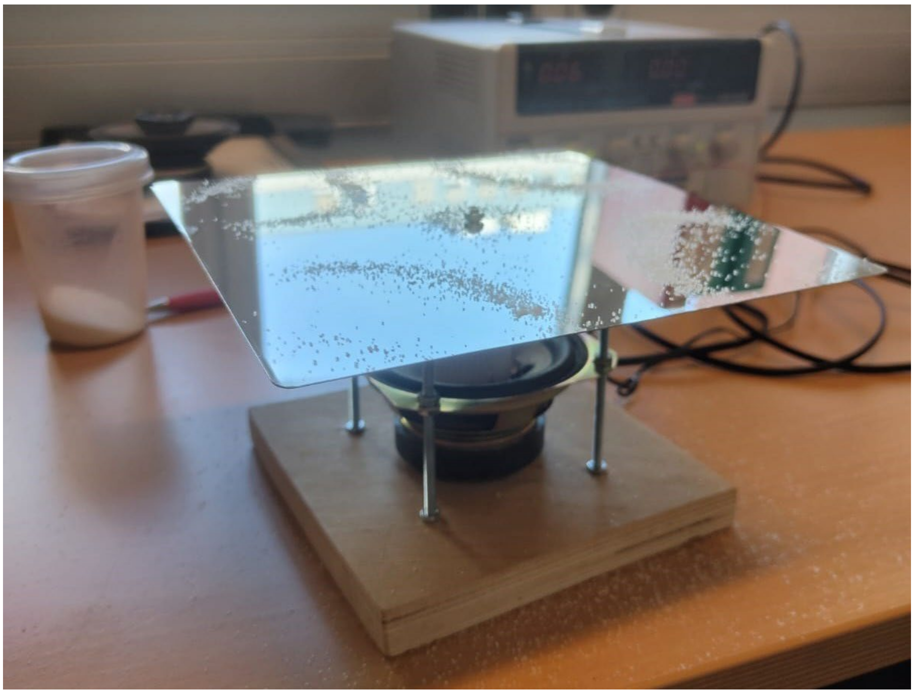


Figure 17: Contact excitation with a modified speaker as vibration generator

The frequency of the sine wave fed into the amplifier can be easily changed with the smartphone, and thus different natural frequencies of the thin metal plate and the corresponding Chladni figures can be generated.

First Experiences and Applications

The work of the student team on this project took place as part of the course *Engineering Projects*, at the end of which there was a presentation of the different works created by all student teams of the class. This presentation took place in the main auditorium of our university and included a PowerPoint presentation followed by a poster presentation. Participants were all students of this academic year as well as all members of the faculty and invited guests from the industry. At the poster presentation, the student teams had to explain their work to the interested visitors and defend their ideas and designs. In the course of such an event, there are usually one or two suggestions for improvement, which can still be incorporated in the remaining time until the end of the project.

The poster of the lightweight design student team is shown in Figure 18, together with an improvised Chladni pattern experiment according to the setup depicted in Figures 15 and 16. Faculty members who teach technical disciplines have already expressed their interest in using this experimental setup in their lectures.

Parts of the experimental setup, which has not yet been completed, have already been used for the first time at the so-called *Long Night of Research*, a nationwide event in Austria in which universities, research institutes and innovative companies are involved. At this event, which takes place once a year and lasts from 5 to 11 p.m., all participating institutions can be visited free of charge by everyone. Visitors are expertly looked after on site, and there is a kind of shuttle service between the locations within a city.

Figure 18: Poster presentation and improvised Chladni pattern experiment

The fact that people of all ages and educational levels have visited our institute allowed conclusions to be drawn about the attraction of the different stations and demonstrations. The contact excitation setup for producing Chladni patterns was highly successful. It performed well during the *Long Night of Research* and demonstrated that this setup, combined with the impact hammer test (Figure 19), effectively engages audiences.

Figure 19: Setup of the impact hammer test at the *Long Night of Research* 2024

As far as the actual addressees of the workshops are concerned, we have not yet gained sufficient experience to be able to propose a defined approach. The participants of the workshops are made up of different age groups and come from different types of schools. So far, we have approached the group dynamics and interests of the children in every school class that has visited us and tried to react to them in the best possible way.

It can at least be said that the simplicity and visual appeal of the Chladni pattern experiment easily capture children's attention. This also proved to be the case when 156 school children from five schools in the region participating in the aforementioned state-funded project visited the university facilities on a field trip lasting four hours. For those with a deeper interest in the topic, the impact hammer test served as a follow-up to illustrate how eigenfrequencies can be determined and how these relate to the stiffness of objects.

It turned out that the time frame of the experiments was also appropriate in view of the decreasing attention span of the younger generation, especially since the children are actively involved in the implementation of the experiments. While no formal evaluation was carried out following this field trip, staff and visiting teachers observed heightened interest amongst the participants.

Summary and Conclusions

In this paper, the development of experiments and an associated experimental setup for the communication of basic ideas on the topic of lightweight design to children and youths were presented. The experiments described here, and various corresponding projects of other institutions, are carried out as part of a state-funded project in the context of workshops at the participating universities and companies.

By engaging a diverse group of young learners in practical, hands-on activities centered around lightweight design, the workshops aim not only to enhance understanding of a specific scientific field but also to foster a set of versatile skills that are essential in the 21st-century educational and professional landscape.

Whether these workshops actually bring the hoped-for benefit in terms of long-term effects on student engagement in STEM activities cannot be evaluated at present. This would require a long-range study and lies beyond the scope of the current initiative. The funded project described here is one of many measures that are being taken by various stakeholders in the region to counteract the increasing shortage of labor, especially in the higher-skilled engineering disciplines. It is naturally in the interest of policymakers to achieve the highest possible percentage of higher-skilled workers in the face of demographic change. Industry is taking the same line, and universities must also make every effort to promote interest in STEM subjects in general and in engineering in particular.

Who undoubtedly benefited from this project, however, are the three graduate students who designed the workshop described here as part of the Engineering Project course. By drawing on their recent coursework and hands-on experiences in lightweight design, the students were able to translate complex engineering concepts into clear, practical demonstrations that could ideally resonate with participants.

This approach not only benefits the workshop attendees but also provided the students with a valuable opportunity to apply their academic knowledge in a real-world context. By engaging in the planning and execution of these workshops, the students gained practical experience in design and project management, while also contributing meaningfully to the broader goal of promoting engineering education among younger generations. Their involvement exemplifies the collaborative spirit of the project, where knowledge is passed down through successive levels of education, fostering a culture of continuous learning and innovation.

Further information and supplementary materials on student projects such as the one presented here are available on our institute's website https://fahrzeugtechnik.fh-joanneum.at/software/.

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