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# GRASPING STRUCTURES:
# AFFORDABLE HANDS-ON COLUMN BUCKLING ACTIVITY FOR FIRST-YEAR ENGINEERING STUDENTS

**Marta Gavioli[1], Giuseppe Radaelli[2], Renate Klassen[1], Annoesjka Cabo[1]**

[1] Faculty of Electrical Engineering, Mathematics & Computer Science, TU Delft
[2] Faculty of Mechanical Engineering, TU Delft

## ABSTRACT

Structural mechanics is a fundamental subject in many engineering curricula. Although its disciplinary knowledge is practice-oriented, i.e., aimed at designing structures, it involves high levels of abstraction and mathematical formalism. Consequently, students often struggle to understand the physical reality behind mathematical formulas. To address this challenge in a first-year mechanical design course with 800+ students enrolled, an affordable demonstrator and a scalable hands-on learning activity were developed. The demonstrator and activity introduce students to fundamental concepts of column buckling and structural stability, guiding them in directly observing physical phenomena, interpreting their observations, and linking their discoveries to disciplinary representations. This paper presents the instructional design of the activity, its implementation in a real first-year classroom environment, and an evaluation of its effectiveness in fostering students' understanding of column buckling concepts. 110 students were present in class and participated in the activity. Students' responses to an online quiz indicate that the activity successfully helped them model their observations using disciplinary representations. Survey responses further show that students perceived the activity as increasing their understanding of the topic and appreciated the opportunity to connect theoretical concepts to real-world phenomena. The study presented in this paper serves as a pilot for a broader initiative aimed at developing similar activities for other mechanics concepts. Accordingly, the suitability of the instructional design methodology and the resulting learning activity format are discussed, offering support for engineering educators seeking to develop similar activities for their courses.

## KEYWORDS

Mechanics, Engineering Education, Practical Activity, Lab, Conceptual Understanding, Standards: 2, 4, 8, 10

## INTRODUCTION

Engineering education often faces the challenge of helping students understand difficult concepts, whose physical meaning is hidden behind abstract and complex mathematical formulas. Hands-On Learning Activities (HOLAs), as a form of active learning, have shown potential in facilitating conceptual understanding [CDIO Standard 8]. However, designing and implementing HOLAs can be daunting, particularly in large first-year bachelor classes (500–1,000 students), due to logistical and financial constraints, combined with a lack of established instructional design methodologies.

To address this challenge, the second author received an educational fellowship to lead an implementation project on “Active Multisensorial Learning in Large Classes” (TUDelft, 2024). The project aims to design a series of small, affordable, and logistically feasible hands-on activities that effectively foster students’ engagement and conceptual understanding. The outcomes of this project are intended to provide practical guidance and examples for other educators at Delft University of Technology (the Netherlands), facilitating the integration of similar activities into their courses [CDIO Standard 10]. This paper presents a pilot study evaluating the suitability and effectiveness of an instructional design methodology for developing hands-on activities in the educational fellowship project. As a starting point, the pilot study focused on a hands-on learning activity addressing the concepts of column buckling and structural stability. The selection of these concepts was primarily a matter of convenience: the second author of this paper was responsible for teaching these topics in an upcoming lecture, making it a practical choice to begin testing the instructional design approach.

At TU Delft, the concepts of column buckling and structural stability are introduced within the first year Mechanical Engineering bachelor curriculum as part of the course "Mechanical Design Project 2" [CDIO Standard 4]. This course, taught in Dutch during the second quarter, enrols approximately 800 students annually. It adopts a project-based approach, where students collaborate in groups throughout the quarter to design a four-wheeled cart, culminating in a competition. In parallel, students attend theoretical lectures on various mechanical design topics, such as material selection, heat treatments, and component sizing. Instead of a textbook, the course provides a formula booklet (Van Beek, 2010) to support the design of mechanical systems. The lectures, held on campus, typically draw an audience of 100 to 200 students. Column buckling is addressed in a single one-hour session during these lectures, with the second author serving as the responsible teacher. The column buckling formulas provided to students in the "Mechanical Design" course are shown in Figure 1.

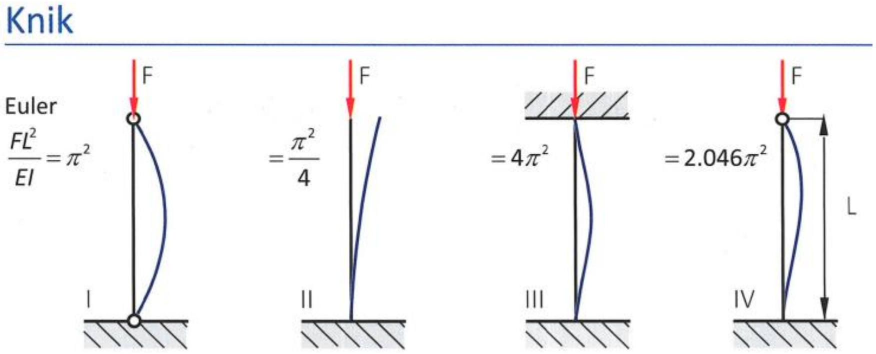

Figure 1 - Disciplinary representations of column buckling [*knik* in Dutch] provided by the formula booklet (Van Beek, 2010)

Column buckling occurs when axial compression acting on a slender structural element exceeds the critical threshold, causing lateral deflection and reducing the load capacity. Below the critical threshold, the column remains stable, but beyond it, the column enters unstable equilibrium, where even minor disturbances can lead to buckling. These concepts are crucial for engineers, who must optimise structural design to prevent or control buckling. Factors such as material properties, length, cross-sectional geometry, and end conditions influence the critical load, which is usually estimated using Euler's formula (Figure 1). While this formula determines the threshold for stable behaviour, it is often mistakenly associated with material strength, such as yield or fracture. However, structural components frequently buckle at loads lower than the yielding point, making buckling an elastic and fully reversible phenomenon. Furthermore, the formulas for buckling do not include material failure parameters, such as yield stress. This ambiguity raises questions about the formula's meaning and its proper application.

Consequently, understanding the phenomenon solely through Euler's formula and the schematics in Figure 1 can be challenging, especially for students with no prior knowledge of these concepts and who have never observed column buckling in real life. Therefore, it was necessary to provide students with the opportunity to directly observe the phenomenon, which was achieved through a hands-on demonstrator. Moreover, the schematics in Figure 1 are "enriched representations" (Fredlund *et al.*, 2014) as they present multiple disciplinary representations (e.g., line and deformed line diagrams, support symbols, force vectors, formulas) layered on top of each other. When introduced to these representations for the first time, students may find certain aspects of the information less accessible or experience information overload. To address these issues, the enriched line diagrams needed to be unpacked—students required guidance to de-rationalize the diagrams and interpret the intended meaning that is not immediately obvious from the representation (Fredlund *et al.*, 2014). To facilitate this process, instructional materials were developed.

Table 1 - Millar's model steps with the related methods and tools used in the pilot study

| ***Millar's model*** | | | |
|---|---|---|---|
| **Stage** | **Name** | **Guiding questions** | **Methods and tools used in the pilot study** |
| A | Intended learning outcomes | What are students intended to learn from this hands-on activity? | Instructional constructs:<br>• pedagogical affordances<br>• unpacking disciplinary representations |
| B | Activity specification | What are students intended to do during the hands-on activity? | Instructional design tools:<br>• Lesson plan template<br>• Interactive lecture demonstration approach<br>• M. Gavioli's design principles<br>• Vevox polls, quizzes, and surveys |
| C | Classroom events | What happened in class?<br>What did students actually do? | Data:<br>• Students' answers to polls and quiz<br>• Independent researcher's observations report<br>• Lesson recording |
| D | Learning outcomes | What did students actually learn? | Data:<br>• Students' answers to related quiz items and final survey |

## INSTRUCTIONAL DESIGN METHODOLOGY

The instructional design methodology follows Millar's (2009) sequential model for developing and evaluating practical activities, particularly in terms of "effectiveness." Table 1 presents the model's steps, their guiding questions, and the methods used in this pilot study. Millar defines effectiveness in two ways: "Effectiveness 1" refers to the extent to which the activity successfully guided students in performing the intended tasks, focusing on the relationship between step C and step B. "Effectiveness 2" refers to the extent to which the activity enabled students to achieve the expected learning outcomes, emphasizing the relationship between step D and step A (Millar, 2009).

### *Methodology for step A: definition of intended learning outcomes*

As emphasized also by CDIO [Standard 2], establishing clear intended learning outcomes (ILOs) ensures that all instructional design efforts are focused on achieving the desired educational goals. ILOs are formulated using Bloom's taxonomy levels and domains (Krathwohl, 2002) to ensure they are observable, measurable, and allow evaluation of the activity's effectiveness (effectiveness in sense 2). In this taxonomy, conceptual understanding, the main educational goal of this study, is defined as the ability to abstract from factual knowledge and comprehend the disciplinary core ideas, principles, and their interrelationships (Krathwohl, 2002).

In this study, the construct of "conceptual understanding" follows the definition provided by Gavioli *et al.* (2020) for mechanics. In this discipline, conceptual understanding involves evidence-based and model-based reasoning skills—the ability to model real-world phenomena, as well as to use real-world evidence to generate and refine models. Since models depend on a broad spectrum of representations to fully capture the salient characteristics of phenomena and their interrelationships (Airey & Linder, 2009) effective conceptual understanding also requires representational competence—the ability to interpret and integrate multiple disciplinary representations (Etkina *et al.*, 2006). This definition had already been successfully implemented in other two case studies (Uriol Balbin & Gavioli, 2024) (Gavioli & Bisagni, 2021).

The specific intended learning outcomes were defined through an analysis of the disciplinary representations in use, particularly the schematics provided in the formula book, as described in the introduction. This analysis identifies the pedagogical affordances of these representations—what students can learn from them, what needs to be unpacked, and any information gaps (Fredlund, Linder & Airey, 2015). These gaps are then addressed by incorporating tasks into the learning activity that guide students in unpacking the initial representations or engaging with additional ones and the demonstrator.

### *Methodology for step B: instructional design of activity specifications*

Once the ILOs are established, the activity specifications are derived, detailing the tasks students must complete to achieve the intended outcomes. These tasks are observable and measurable, enabling an evaluation of the activity's effectiveness (effectiveness in sense 1). The specifications summarize the lesson plan, activity segments, and instructional materials.

#### *Design of the lesson plan and activity segments*

The lesson plan template outlines the lesson's segments, their durations and the needed materials. It is iteratively refined during the instructional design process. In this study, activity segments follow the Interactive Lecture Demonstration (ILD) approach (Sokoloff & Thornton, 1997), an active learning strategy aimed at fostering student engagement and enhancing understanding of physical phenomena. ILD structures the activity into three phases: predicting, observing, and reflecting. Each segment aligns with the learning objectives, guiding students' attention to key concepts before, during, and after the hands-on activity.

Since the activity aims to foster conceptual understanding, the 'observing' segment's tasks are designed according to the principles of Gavioli *et al*. (2020):

1. Adopt guided inquiry-based instruction.
2. Allow direct experience of phenomena.
3. Incorporate diverse disciplinary representations.
4. Encourage the intertwining of experienced events and theoretical concepts through targeted learning tasks.
5. Monitor and guide students' progression from experience to theoretical models.

*Instructional materials using the Vevox platform*

For this pilot study, the real-time audience engagement platform Vevox (2024) was selected, as it is available free of charge to TU Delft staff. Three Vevox tools were utilized: *polls,* where students answer questions using their phones as clickers within a set timeframe, with responses displayed live on the classroom screen for immediate discussion; *quizzes*, which allow students to access an online environment via their phones to complete all questions before submission, after which they can view their scores and receive automated feedback; and *surveys*, which function similarly to quizzes but are ungraded. Each of these Vevox tools is implemented in a lesson segment as follows: predict segment – polls; observe/model segment – quiz; reflect segment – survey.

Vevox enables the export of student responses into Excel, facilitating faster data analysis compared to traditional paper-based activity sheets. However, the platform also imposed certain limitations on the types of tasks students could perform, such as the inability to support diagram drawing. Additionally, it was decided to collect students' answers anonymously—no personal data was recorded by the Vevox platform. In this case, the platform assigns each student an identification number, which allows tracking of their performance across different tasks (poll, quiz, survey). These affordances and constraints of the digital platform were considered as additional boundary conditions in the instructional design.

### *Methodology for step C and D: classroom events and learning outcomes evaluation*

Step C evaluates what students did during the session by analysing their anonymous responses to the Vevox poll and quiz. Additional observational data were collected and analysed for this pilot study, including a video recording of the lesson (captured via the university's streaming platform, Collegerama) and written observations from an independent researcher who attended the lecture. These supplementary data collections were used to validate the analysis of student behaviour only for this pilot study. Due to space constraints, the observational data are not detailed in this paper.

Step D evaluates what students learned by analysing their anonymous responses to the Vevox survey. Students rated their perceived achievement of the ILOs and the extent to which the hands-on activity increased their interest in the topic using a 5-point Likert scale (1 to 5 stars). To gain further insights into the learning outcomes, an open-ended question was included. Selected student responses are quoted and commented upon in the results and discussion section.

## RESULTS AND DISCUSSION

### *Step A and B: the designed learning activity*

The hands-on column buckling activity was designed to achieve the following goals:

What are students intended to learn from this hands-on activity? (step A, Table 1)

**ILO1:** Students will be able to recognize observable factors that characterize the buckling behavior and patterns in observations; specifically the relationship between support conditions and both buckling load and deformed shape. *Level 1 – Remember*

**ILO2:** Students will be able to apply theory (i.e. disciplinary representations) of column buckling to describe real-world experience and observations. *Level 3 – Apply*

**ILO3:** Students will be able to explain the column buckling phenomenon and its most important aspects. *Level 2 – Understand (overall conceptual understanding of the buckling phenomenon)*

To give students direct experience and insights into the column buckling phenomenon, the second author developed the "column buckling demonstrator," shown in Figure 2. Designed to minimize cost and enable quick manufacturing, the demonstrator uses common materials from the mechanical engineering faculty workshop, allowing each student in the class to have their own unit.

Figure 2 - Column buckling demonstrator

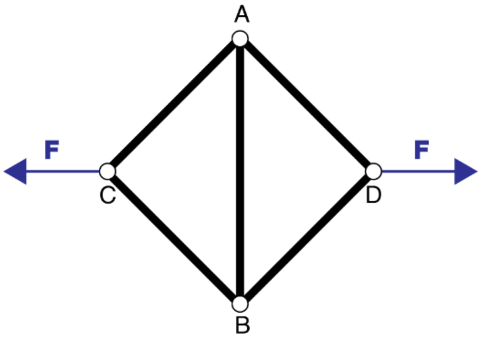

Figure 3 - Analogous mechanism to the buckling load demonstrator

The demonstrator features a 3D-printed ring with slits of varying shapes on its inner edge, which support a slender metal bar. When the sides of the 3D-printed ring are pulled apart, the two supporting points move closer together, as the ring functions as a compliant inverter mechanism (Figure 3). This mechanism converts the applied tensile force, which is much easier for human arms to apply without unwillingly introduce other forces and moments, into the compressive force needed for buckling. The slits in the ring are designed to serve as either fixed or pinned supports, enabling the demonstrator to provide the following support conditions: pinned-pinned, fixed-fixed, and pinned-fixed. Technical drawings and 3D printing files are available upon request from the corresponding author.

Table 2 presents the final lesson plan, outlining the intended learning outcomes for each segment and the materials required to support the activities. The final column of Table 2 provides a summary of the developed instructional materials, which are detailed in full in the Annex to this paper. All instructional materials have been developed in English.

Table 2 – Lesson plan for the hands-on activity on column buckling

| Segment | Dur. | Goal | Material | Vevox Items |
|---|---|---|---|---|
| **1.**<br>Welcome, introduction to stability and column buckling | 20 min | Warm up.<br>Introduce main concepts to be learned (ILO3).<br>***Predict*** demonstrator behaviour. | Classroom screen:<br>• PowerPoint slides<br>• Vevox Poll<br>Students' personal phone / laptop:<br>• Vevox Poll | ***5 polling items (P01-05):***<br>• 2 about concept of stability<br>• 3 about modelling the behaviour of the hands-on demonstrator |
| **2.**<br>Column buckling hands-on activity | 20 min | Directly experience column buckling and notice its important aspects (ILO1),<br>***Observe/model*** (ILO2) | One column buckling demonstrator per (group of) student(s)<br>Students' personal phone/ laptop:<br>• Vevox quiz | ***11 quiz items (O01-11):***<br>• 2 about the student team composition<br>• 6 about reporting and interpreting the observations<br>• 2 only about theory/ modelling<br>• 1 metacognitive |
| **3.**<br>Transfer and reflection | 20 min | Discussion on exam exercises.<br>Support transfer of learning to new situations for which the concept applies/ ***Reflect*** (ILO3) | Classroom screen:<br>• PowerPoint slides<br>Students personal phone/ laptop:<br>• Vevox survey | ***8 survey items (R01-08):***<br>• 4 Linkert items, 1 multiple choice and 1 open question on perceived learning outcomes<br>• 2 open questions for feedback |

Finally, the activity specifications are outlined below as a list of tasks that students are expected to perform during the lesson to achieve the intended learning outcomes.

What are students intended to do during the hands-on activity? (step B, Table 1)

**SP1:** Actively participate in the polling activity
**SP2:** Engage with the column buckling demonstrator
**SP3:** Answer to the observe/model quiz questions
**SP4:** Correctly report their observations

*Discussion on the instructional design of the activity*

To ensure students' conceptual understanding, the activity's instructional design follows Gavioli et al.'s principles (detailed in the methodology). Guided inquiry-based instruction (1) is consistently applied throughout the activity, encouraging students to engage in exploration and collect their own observations. They directly experience column buckling (2) using the hands-on demonstrator, bypassing mathematical formulas. Diverse disciplinary representations are incorporated in the activity (3), such as free-body diagrams and illustrations of different end support cases. Targeted learning tasks help students link their direct experiences with theoretical concepts (4), using discipline-specific diagrams and symbols (e.g., types of supports) to record their observations of real-world objects and events. Finally, students' progression from experience to theory is monitored and guided (5) through explicit requests, mostly in the form of multiple-choice questions asking them to “model” or describe their observations. This process follows the usual sequence of engineering modelling and testing: differentiating the body under study from its environment, modelling boundary conditions, applying the load (running the test), recording observations (e.g., the magnitude of the buckling load and comparisons between different cases), and reporting the buckling shape.

### *Step C and D: classroom events, learning outcomes, effectiveness 1 & 2*

In January 2024, the hands-on activity was implemented in the "Mechanical Design" course, with 110 students present in class that day. Students were informed that participation in the data collection was voluntary, anonymous, and not graded. The lecturer then introduced column buckling with slides and engaged students using Vevox polling questions. Students' responses were discussed for clarity. Materials for the hands-on activity were distributed, with minimal instructions provided, and students completed a Vevox quiz either alone or in groups. The lecture concluded with exam tips, though the reflective survey was rushed due to time constraints, which has affected the response rate. In the Annex to this paper, students' responses per each item of the poll, quiz and survey are reported. In the following sections main results are discussed.

*What did students actually do during the activity? (step C, Table 1)*

***SP1:*** All 110 students logged into Vevox, ensuring full class participation in the polling activity. On average, 83.8% of students responded to the polling questions, with participation ranging from 77.3% to 90%, indicating high engagement. ***SP2:*** Students actively interacted with the column buckling demonstrator, as recorded by the independent researcher. A total of 86 quiz responses were submitted, reflecting a mix of individual and group work. ***SP3:*** The average response rate for the quiz was 78.2%, with nearly all students completing the 'observe' and 'model' items (O03 to O10). ***SP4:*** Students demonstrated strong observational accuracy, correctly reporting their observations 95.6% of the time for 'observe' items (O03, O06, O07, O08, and O09). In the 'model' section, most students correctly identified structural supports: 74 correctly selected a "pinned" support for O04 (9 chose "roller"), and 84 correctly identified the "fixed" support in O05. These results suggest that while students were generally able to model supports, distinguishing between pin and roller types was more challenging. Overall, these results provide compelling evidence that all four intended tasks outlined in the activity specifications (SP1 to SP4) were actually performed.

*What did students actually learn? (step D, Table1)*

Of the 110 students present in class, 30 completed the reflection survey, which included four Likert scale items, a multiple-choice question (R05), and an open question (R06). The full text items and related responses are in the Annex to this paper. Using a 5-point Likert scale (1 = strongly disagree to 5 = strongly agree), students rated their agreement with four statements: R01, R02, and R03 assessed the perceived achievement of ILO1, ILO2, and ILO3 respectively, while R04 measured increased interest in the topic. Figure 4 presents students' responses. 97% of students agreed or strongly agreed that the activity helped them understand column buckling (R03; ILO3). For R01 and R02, 100% agreed or strongly agreed that the activity enabled direct observation of the phenomenon (ILO1) and helped relate theory to experience (ILO2). R04 had the highest neutral and disagreement responses (43%), with 13 students stating the activity did not increase their interest in the topic. The authors suspect this feedback reflects students' general lower motivation for theoretical lessons in a project-based course like Mechanical Design Project 2, where design work and teamwork take priority. This assumption will be explored in future research. Finally, 29 of 30 students reported learning something new from the activity (R05). Sixteen students also answered the open question (R06), providing further insights into the achievement of the intended learning outcomes. Students appreciated new aspects of the phenomenon ('Buckling happens when you compress a beam, and it's easier for the beam to deform in a different direction than the direction of the compression.'), applied theory to describe real-world experience ('Fixed supports need more force than pinned supports to make the beam buckle') and, in general, understood the its main aspects ('Different supports have different properties and formulas'). The activity also helped students associate the buckling concept with the threshold for stable behaviour rather than material failure (‘Buckling is a phenomenon and not a problem” ‘It’s about elasticity’). Overall, the outcomes of step D indicate the activity was effective also in sense 2, i.e. students learnt what they were intended to. The low survey response rate, due to implementation issues in this pilot study, will be addressed by integrating the ‘reflect’ items into the observe/model quiz in future iterations.

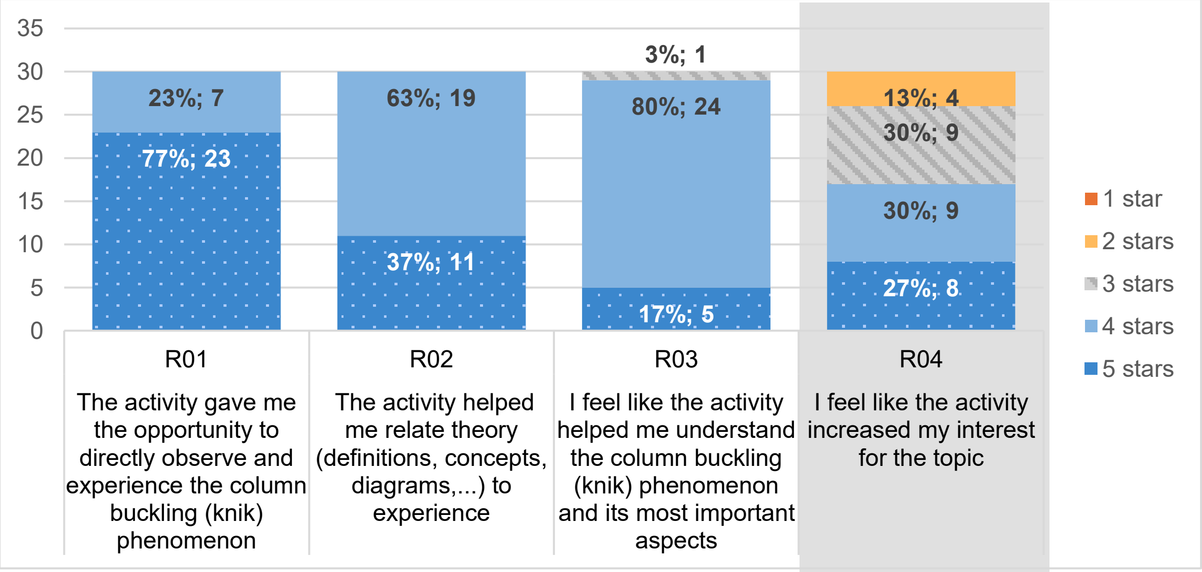

Figure 4 - Students' responses to Likert scale items of the survey.

## CONCLUSIONS

The aim of this pilot study was to evaluate the suitability of an instructional design methodology for developing affordable and logistically feasible hands-on activities within an educational fellowship project. These activities aim at fostering students’ engagement and conceptual understanding of mechanics and physics. The learning activity developed for the pilot study introduced first-year engineering students to column buckling in just one hour. The findings confirm that the employed instructional design methodology successfully supports both student engagement and conceptual understanding of the phenomenon. This structured approach is well-suited for scaling up and adapting to other hands-on activities in engineering education, including those planned for the educational fellowship.

Given the positive outcomes of this pilot study, several key lessons can inform the development of hands-on activities for other mechanics and engineering concepts. First, relevant disciplinary representations and their pedagogical affordances must be carefully identified. This ensures the formulation of meaningful and detailed learning objectives. Second, the use of Interactive Lecture Demonstrations, combined with observation and modelling tasks grounded in Gavioli et al.'s principles, provides a clear and structured methodology for designing engaging learning tasks. Specifically, multiple-choice questions formulated in a guided-inquiry style proved particularly effective in guiding students perform real-world observations and link them to theoretical concepts. Additionally, the demonstrator’s low-cost design and the integration of a real-time audience engagement platform ensure scalability to larger class sizes. Finally, comparing activity specifications to classroom events and intended learning outcomes to students’ perceived ones provides a feasible way to evaluate instructional effectiveness in real classroom settings. Given the challenges educators face in designing hands-on activities that enhance students' conceptual understanding of mechanics, this methodology provides a practical, evidence-based guide that can inspire and support engineering educators.

## ACKNOWLEDGEMENTS

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## BIOGRAPHICAL INFORMATION

***Marta Gavioli*** holds a MSc degree in Electrical Energy Engineering, and she is a PhD candidate in the field of Engineering Education. Her research project focuses on hands-on learning in structural mechanics for conceptual understanding. From October 2021 to September 2024 she led PRIMECH: the PRogramme of Innovation in MECHanics education at TU Delft, a university-wide initiative to innovate bachelor-level mechanics education together with the mechanics teachers. As such, she holds extensive expertise in developing tailored learning activities, educational projects, workshops and events. *ORCID: https://orcid.org/0000-0003-1690-8235*

***Giuseppe Radaelli*** holds a MSc degree and a PhD degree in Mechanical Engineering from Delft University of Technology, where he is currently employed as an Assistant Professor. In 2024 he received an Education Fellowship award from the TU Delft to foster his efforts in trying to increase active participation in very large sized lectures (800+ students) by means of physical demonstrations and experimentations. *ORCID:* https://orcid.org/0000-0002-2935-3868

***Renate Klassen*** studied English Language and Literature and International Management, earning a PhD from TU Delft in 2001 on English-medium Instruction in HE. She is currently a Senior Policy Advisor for the TU Delft Graduate School and a Senior Researcher at the Delft Institute of Applied Mathematics (PRIME research group). She also serves as guest editor for a *Frontiers in Education* special issue on "Epistemological Fluency in Interdisciplinary Learning". Her research interests include mathematical competencies as a tool for curriculum development, the transfer of math towards engineering education, AI in math education, gender differences in math education, and interdisciplinary learning. In PRIME, she supervises PhD candidate M. Gavioli. *ORCID: https://orcid.org/0000-0001-7293-3668*

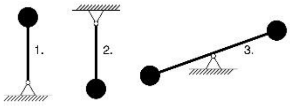
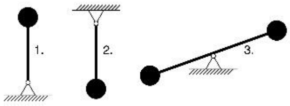
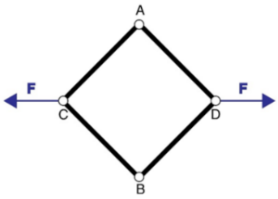
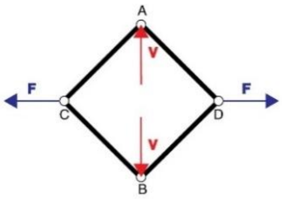
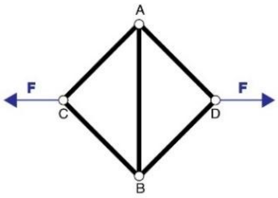
***Annoesjka Cabo*** studied Mathematics at the University of Amsterdam and earned her PhD from TU Delft in Stochastic Geometry. Since 2012, she has taught mathematics courses at TU Delft. From 2016 to 2021, she was Director of Studies for Interfaculty Education and led the Programme of Innovation in Mathematics Education (PRIME). Currently, she is a Professor in Statistics for Innovation in Education. Since 2019, she has been the Academic Director of the TU Delft Teaching Academy, and since July 2021, she has served as the Director of Education at the Faculty of Electrical Engineering, Mathematics, and Computer Science. Since 2023, she has been part of the Innovation in Delft Engineering Education (IDEE) Advisory Board. She leads the PRIME research group and is M. Gavioli's PhD promoter. ORCID: https://orcid.org/0000-0002-8305-9993

### ***Corresponding author***

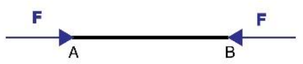
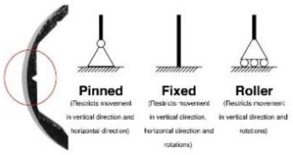
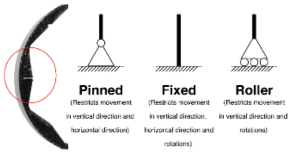
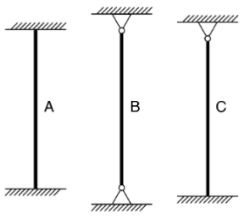
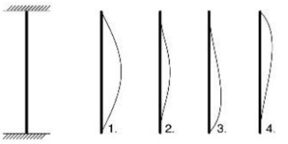
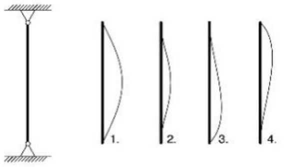
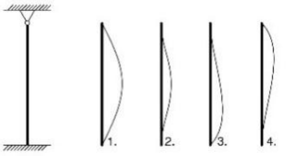
Giuseppe Radaelli
Delft University of Technology,
Faculty of Mechanical Engineering
Mekelweg 2, 2628CD Delft
NETHERLANDS
g.radaelli@tudelft.nl

## ANNEX 1: INSTRUCTIONAL MATERIAL AND STUDENTS' PERFORMANCE

### Table 3 - Transcript of the Vevox polling items and students' responses

| ***PREDICT SEGMENT*** | | | | | |
|---|---|---|---|---|---|
| *Nr:* | *Type:* | *Question (in **bold** the correct answers):* | | *Nr Part:* | *Students' responses* |
| P01 | Multichoice (3 allowed responses) |  | Which systems are in equilibrium (evenwicht)? System **1, 2** or 3? | 99/110 (90%) | **1. System 1: 77 (70%)**<br>**2. System 2: 99 (90%)**<br>3. System 3: 67 (60.9%) |
| P02 | Multichoice (3 allowed responses) |  | Which systems are stable (stabiel)? System 1, **2** or 3? | 90/110 (81.8%) | 1. System 1: 6 (5.5%)<br>**2. System 2: 88 (80%)**<br>3. System 3: 23 (20.1%) |
| P03 | Multichoice (1 allowed response) |  | Given that all the beams in this system have equal length, if you pulled point C and D so that they move apart, what would you expect to happen to point A and B?<br>**1. They move closer**<br>2. They move apart | 93/110 (84.5%) | **1. They move closer: 91 (82.7%)**<br>2. They move apart: 2 (1.8%) |
| P04 | Multichoice (1 allowed response) |  | What should be the relation between force F and force V to have equilibrium?<br>1. V should be stronger than F<br>2. V should be weaker than F<br>**3. V and F should be the same** | 94/110 (85.4%) | 1. V should be stronger than F: 1 (0.9%)<br>2. V should be weaker than F: 9 (8.2%)<br>**3. V and F should be the same: 84 (76.4%)** |
| P05 | Multichoice (4 allowed responses) |  | If you applied a compressing force to this steel slender beam (AB), you would expect it to...(multiple options apply):<br>**1. Shrink**; 2. Elongate;<br>**3. Bend**; 4. Else | 85/110 (77.3%) | **1. Shrink: 73 (66.4%)**<br>**2.** Elongate: 5 (4.6%)<br>**3. Bend**: 57 (51.8%)<br>**4.** Else: 20 (18.2%) |
| Avg. | | | | 92,2/110 (83.8%) | |

## Table 4 - Transcript of the Vevox quiz items and students' responses

| *OBSERVE / MODEL SEGMENT* | | | |
|---|---|---|---|
| *Nr:* | *Type:* | *Question (in **bold** the correct answers):* | *Students' responses* |
| O01 | Logistics* | Your group is composed of how many students? | Total sum: 112* |
| O02 | Logistics* | You are answering these questions...<br>1. only for yourself<br>2. also for the rest of the group | 1.: 34*<br>2.: 20* |
| O03 | Multichoice (3 allowed responses)<br>Observe |  <br>When you apply a compressing force F to the steel slender beam (AB), you can see the beam...<br>1. Shrinking 2. Elongating<br>**3. Bending** | **Bending: 75/86 (87.2%)**<br>Shrinking: 1/86 (1.2%)<br>**Bending + shrinking: 7/86 (8.1%)**<br>Elongating: 3/86 (3.5%) |
| O04 | Multichoice<br>Model |  <br>What type of support does best describe the support this slit provide?<br>**1. Pinned** 2. Fixed 3. Roller | **Pinned: 74/86 (86%)**<br>Fixed: 3/86 (3.5%)<br>Roller: 9/86 (10.5%)<br>No reply: 1/86 (1.2%) |
| O05 | Multichoice<br>Model |  <br>What type of support does best describe the support this slit provide?<br>1. Pinned **2. Fixed** 3. Roller | Pinned: 0/86 (0%)<br>**Fixed: 82/86 (95.3%)**<br>Roller: 4/86 (4.7%) |
| O06 | Rank in correct order<br>Observe |  <br>How much compression force is needed to make the beam buckle (knik)?<br>Select the supports configurations (A;B;C) in order, from the one that requires the stronger force to the one that require the weakest.<br>[correct answer: **ACB**] | ABC: 2/86 (2.3%)<br>**ACB: 78/86 (90.7%)**<br>BCA: 5/86 (5.8%)<br>CBA: 1/86 (1.2%) |
| O07 | Multichoice<br>Model + observe |  <br>When the beam is between these two supports and the compression force is applied, what shape does it take?<br>shape 1; **shape 2**; shape 3; shape 4 | shape 1: 2/86 (2.3%)<br>**shape 2: 84/86 (97.7%)**<br>shape 3: 0/86 (0%)<br>shape 4: 0/86 (0%) |
| O08 | Multichoice<br>Model + observe |  <br>When the beam is between these two supports and the compression force is applied, what shape does it take?<br>**shape 1**; shape 2; shape 3; shape 4 | **shape 1: 84/86 (97.7%)**<br>shape 2: 2/86 (2.3%)<br>shape 3: 0/86 (0%)<br>shape 4: 0/86 (0%) |
| O09 | Multichoice<br>Model + observe |  <br>When the beam is between these two supports and the compression force is applied, what shape does it take?<br>shape 1; shape 2; shape 3; **shape 4** | shape 1: 1/86 (1.2%)<br>shape 2: 0/86 (0%)<br>shape 3: 2/86 (2.3%)<br>**shape 4: 83/86 (96.5)** |
| O10 | Multichoice<br>Observe | Once the compression force was no longer applied, the beam...<br>1. Returned to the original state (elastic deformation)<br>2. Remained deformed (plastic deformation) | 1.: 86/86 (100%)<br>2.: 0/86 (0%) |
| O11 | Text Metacognit. | In your opinion, what is the purpose of this hands-on activity? | / |

* Quiz items O01 and O02 were designed to track students' decisions and accurately account for responses. A total of 54 quizzes were submitted: 18 by individual students and 36 by students working in groups. Among the group-working students, 15 respondents indicated that they were answering the questions only for themselves. Summing

the numeric answers for O01 resulted in 112 students, suggesting more than one student per group had submitted the quiz. Therefore, the 15 individual responses were counted as separate, while the 21 group responses were multiplied by group size, resulting in 86 students submitting quizzes out of 110 present in class.

**Table 5 - Transcript of the Vevox survey items and students' responses**

| *REFLECT SEGMENT* | | | |
|---|---|---|---|
| *Nr:* | *Type:* | *Question:* | *Students' responses* |
| R01 | Rating<br>1 - 5 Stars | The activity gave me the opportunity to directly observe and experience the column buckling (knik) phenomenon | 4 stars: 7/30 (23%)<br>5 stars: 23/30 (77%)<br>Average: 4,77 stars |
| R02 | Rating<br>1 - 5 Stars | The activity helped me relate theory (definitions, concepts, diagrams,...) to experience | 4 stars: 19/30 (63%)<br>5 stars: 11/30 (37%)<br>Average: 4,37 stars |
| R03 | Rating<br>1 - 5 Stars | I feel like the activity helped me understand the column buckling (knik) phenomenon and its most important aspects | 3 stars: 1/30 (3%)<br>4 stars: 24/30 (80%)<br>5 stars: 5/30 (17%)<br>Average: 4,13 stars |
| R04 | Rating<br>1 - 5 Stars | I feel like the activity increased my interest for the topic | 2 stars: 4/30 (13%)<br>3 stars: 9/30 (30%)<br>4 stars: 9/30 (30%)<br>5 stars: 8/30 (27%)<br>Average: 3,70 |
| R05 | Multichoice | Have you learnt anything new today?<br>yes / no | Yes: 29 (97%)<br>No: 1 (3%) |
| R06 | Text | Can you name the most important thing(s) about buckling (knik) you learnt today, if any? | 16 responses; See **Error! Reference source not found.** |
| R07 | Text | Do you have any suggestion on how to improve the activity? | 8 responses |
| R08 | Text | Do you have any additional comment? | 8 responses |

**Table 6 - Students' responses to the survey item R06 - open question.**

*R06: Can you name two of the most important things you learnt today, if any?*

1. *Stijfheid [stiffness].*
2. *How support influence it.*
3. *That the knik is the elastic movement, and how big the difference is between support types. The hands on part made that easier to grasp.*
4. *It is only determined by the E value (and dimensions) of the material & changes when the supports are different.*
5. *Buckling happens when you compress a beam and its 'easier' for the beam to deform in a different direction than the direction of the compression. Fixed supports need more force than pinned supports to make the beam buckle.*
6. *It's never 100% accurate because it's an unstable phenomenon.*
7. *That it happens at weaker points.*
8. *It's about elasticity.*
9. *The formulas provided gave me a better understanding of how the various situations in which buckling can occur compare to each other.*
10. *It is the instability of a state and not the actual deformation.*
11. *The shape in which the column buckles is effected by the support.*
12. *Building is knik.*
13. *That buckling is a phenomenon and not a problem. Buckling should be evaluated rather than prevented.*
14. *I learned that different supporters have different resistances (minimum applied forces) for knik and that knik isn't always a negative property/phenomenon.*
15. *Buckling is instable.*
16. *Different supports has different properties and formulas.*