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A Student-Centered Active Learning Approach to Teaching Structures in a Bachelor of Architecture Program

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Abstract

Nearly all programs of architecture focus on structures as independent coursework, rather than on integrating pedagogy (i.e. how to teach structures in studio). To fill this gap, an innovative freshman workshop was developed in this study with a student-centered active learning approach to teach structures. In the present study, this approach combines three types of active learning activities: think-pair-build; in-class, all comrades' shared discussions and review; and articulated student development reflections. The primary vehicle used for discovery is the Workshop Method. By focusing primarily on student's own creative genre (small group designs), the class responds to what is brought into the one period focus. Workshops are devoted to critiquing work, to generating new work through guided exercises and assignments, and to incorporating a combination of both approaches for instilling intellectual habits. This approach implemented and assessed in three workshops in a freshman studio (three semesters) at the Division of Architecture, University of Oklahoma by architectural and structural faculty and their graduate assistants.

The results show that this method was a fairly successful structures introduction into architectural form, not previously considered. Specifically, in pre-structure workshop survey, student observations on structural components not reflected. Later, in post-structure workshop surveys, much is retained from structural information from the two workshops. Then, by faculty observation, in final end-of-the-year studio reviews, studio projects demonstrated structure patterns in comparison to previous years' form-only outcomes. It is assumed that the structural activities in studio provided the students with added reinforcement in understanding how structural components work in design. From this first trial run, results prove integrating workshops and active-student learning techniques early influence students' knowledge and understanding of structures. Further research currently conducted to follow these freshmen students through their second-year matriculation in the program. The study will examine if these same architecture students: (1) retain and use structures in their designs long before they actually take traditional structure curriculum coursework in their third year; and (2), if structural components appear in their work. This study implies that the most effective method for students to learn how to develop an integral structural process in their work (pattern and strategy) is learning by doing in freshman studio.

Introduction

The importance of foundational structural knowledge for architecture students is manifested in the following three aspects. First, the earmark of their profession, to secure health, safety (structural integrity) and welfare in their professional projects. Second, the nature of the construction industry at large today, to design and build complex building projects with the skill to contribute collaboratively (to discuss options with consulting engineers). Third, in architectural curriculums, to have structural skills may be among the highly important skills for passing the Architectural Licensing Exam in the United States. An untapped resource in the architectural design process as a major creative venue is architectural structural awareness. Authors believe this is a problem.

In conducting research on first and second year students, early introduction of structures did not hinder design creativity, but it instead made their designs more practical and realistic. In juxtaposition, previously, structural education obtained from advanced, not early, undergraduate technical silo coursework. In fact, the current emphasis on these courses is to teach students to calculate loads and member sizes, rather than how to design systems into their processes and form. This implies structural knowledge is a specialty, not integral to the architectural mindset.

Clearly, the most innovative and inspired works of architecture are the ones with a creative structure that informs the project, and well. For example the famous architects like Frank Lloyd Wright, Frank Gehry, Louis I. Kahn, Renzo Piano, Rem Koolhaas, and Santiago Calatrava have designed buildings and bridges with advanced structural systems. These architects have highly developed their advanced understanding of technology, structure, and materials in their magnificent designs. Here are some of the superior buildings designed by the famous architects; Falling Water, U.S. (1939) designed by Frank Lloyd Wright, Resaurante Los Manantilaes, Xochimilco, Mexico (1957) designed by Felix Candela, Lyon-Saint Exupéry Airport Railway Station, Saugnieu France (1994) designed by Santiago Calatrava, and Auditorium Parco della Musica, Italy (2002) designed by Renzo Piano.

According to Salvadori (1986), architects and engineers must collaborate in design. Therefore, they need to have a common vocabulary to be able to work together successfully. The architect must have knowledge in structural analysis and design influenced by the engineer (Lonnman 2000). Certainly, structural knowledge is fundamental to the design process and architectural expression (Wetzel 2012). This fundamental must be developed from school when architect students begin learning about design and structure. Nearly, structures is taught as an independent course, rather than integrating pedagogy. One of the reasons behind this might be that architecture students must have structural skills to be able to pass the Architectural Licensing Exam in the United States. Therefore, the focuses in structural courses are to learn how to calculate loads and design elements with different materials, rather than how to design systems into their processes and form. Consequently, this method creates a gap between studio and structure course.

It has been a big challenge for many instructors to consider the importance of visualization to teach structures. Therefore, instructors investigated innovative teaching methods such as using physical models, digital model, and finite elements of structures. For example, Black and Duff (1994) used advanced structural engineering software, finite elements, to teach structures to architecture students. Students used the computer software to analyze small and large buildings and compare those with their hand calculations. Vassigh (1994 and 2005) developed a new program to teach structure to architecture students. The program was digital models to show the load-collection mechanism and load distribution path through the structural systems. This program animated the load path in the entire structure to help students visualize the behavior of structural system.

Lonnman (2000) used three types of structural models to help architecture students visualize structural behavior of structures' design. A three-dimensional diagram was also used to study the geometry, scale, and load path of structural system. Unay and Ozmen (2006) believed that it is the responsibility of the practicing architects to integrate the structural system to architectural design. Therefore, they had their students work with the help of real-life, structure instructors, and computer to create structural models in their design studio. Unay and Ozmen (2006) note that many architects in the industry assume

structures to be a technical component that must be left to engineers alone. In an effort to counter this type of thinking and to better reinforce structures among architecture students; the primary method used for discovery is the Workshop Method. For the test group of first year students, we it was decided to conduct a fall, and spring, introductory presentation series of structural elements and components. According to Wetzel (2012):" integrating structures and design helps students to develop their design studio with an understanding of materials and structural systems." Therefore, Wetzel introduced dynamic modeling techniques and large-scale installations to help students visualize structures and integrate structural systems in their design studio. Fami, Aziz and Ahmend (2012) conclude that, "In order to achieve such collaboration goal, the visual approach in teaching is the appropriate method for architectural students."

This study implies that learning by doing is the most effective method for students to learn to develop an integral structural process in their work (pattern and strategy). For the purpose of this study, three types of learning activities were combined: think-pair-build; in-class, all comrades' shared discussions and review; and articulated student development reflections.

In an effort to better reinforce structures among architecture students, we researched and assessed different types of methods to teach structures. With the advisement of other professors, and multiple discussions relating civil engineering coursework to architectural, a blended method of teaching structures was employed. Therefore, two workshops format were developed in a freshman studio (two semesters) at the Division of Architecture, University of Oklahoma by architectural and structural faculty and their graduate assistant. The objective was to review work, to generating new work through guided exercises and assignments, and to incorporating a combination of both approaches for instilling intellectual habits.

Both presentations workshops were to be preceded by a survey that asked basic structural questions. The goal was to test how well the students thought of structural elements before and after being introduced to the material. Following each presentation, an exercise that was intended to help the students conceptualize structural components was conducted and a similar survey was given to the students again to see if their level of understating structures changed.

Workshop 1: 2017 Fall Semester Trial I Overview

For the fall semester, first a pre-survey was given to the students to fill out individually. The survey included basic questions about structural elements and structural system. The pre-survey included four structural questions, two multiple choices and two short answer. Figures 1 and 2 show two of the survey questions for this workshop. The rest of the questions have been followed after Figures 1 and 2. After the pre-survey, the structural professor provided an introductory presentation series in a PowerPoint format. The presentation consisted of a brief introduction to structural elements and components, structural system, materials, type of loads focusing on gravity load, description of a floor plan for the surveys, and introduction for the exercise. Then, the exercise the students participated in was the egg drop test.

Each student was put in a group of four to five and given supplies to construct a small structure that was intended to protect a raw egg. The finished design was to be dropped from a fixed height of approximately 10 feet. The group's designs were left completely up to their creative imagination. Each group had many different structural variations within their designs. During the actual egg drop, students were able to visualize just how a design can impact the strength and safety of a structure. At the end, after testing, the same survey given to the students

to gather data and then compare the responses before and after.

In comparing the surveys, students demonstrated a higher selection of metal materials chosen after the presentation and the egg drop exercise. It appears that students associated metal with being a stronger material for column and beam construction. Many of the students had a gist of metal equating to strength, however, they could not quite distinguish that iron and aluminum are not materials that should be used in beam and column construction.

Votes for marble as an acceptable structural material dropped from survey one to survey two. Students seemed to understand that marble is not a structurally sound material capable of column and beam construction; however, it appears they still chose marble due to the association with its historical aesthetic use, rather than structural use.

In the short answer post survey question, students showed some understanding of how a structure should perform. Many of the student's answers contained a short analysis of how the structural components keep the building standing during impact and/ or load increase. Students also realized that structures that seem to be designed well did not perform the best, structurally. Students also identified that structures using heavier material were not always the better designs. Lastly, they observed that lighter material was favorable for optimization and was more efficient.

Many students were intrigued by how structures are inspired by nature and natural elements. The questions for surveys and analysis presented in following section.

Fall Pre- and Post- Survey Results and Analysis

Question 1: Which building type out of the four listed- have you noticed the design of the structural system?

For Figure 1, Question 1; the answers varied with selections of what structural system has been most noticeable to the students. The parking garage structural system maintained the highest selections throughout survey 1 and 2.

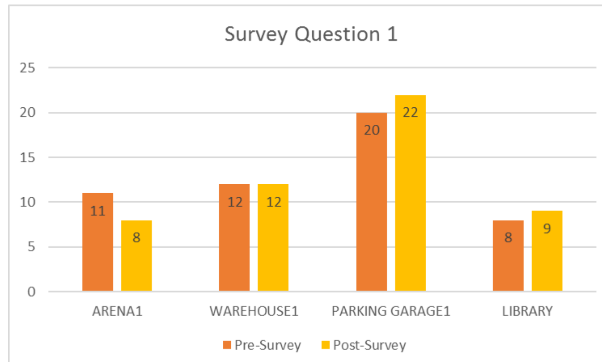


Figure 1: Students' answers to question one pre-survey and post-survey.

Question 2: What are acceptable materials to use for column and beam construction?

From Figure 2, Question 2- In comparing the surveys student exhibited answers having a higher selection of metal materials after the presentation and the egg drop exercise. First year students also appear to associate all metal with strength and favorable column and beam construction. Lastly, students cannot distinguish that iron and aluminum have a lower psi and are not materials that should be considered in beam and column construction.

Votes for marble as an acceptable structural material dropped from survey one to survey two. Students seemed to understand that marble is not a structurally sound material capable of column and beam construction; however, it appears they still chose marble due to the association with its historical aesthetic use, rather than structural use.

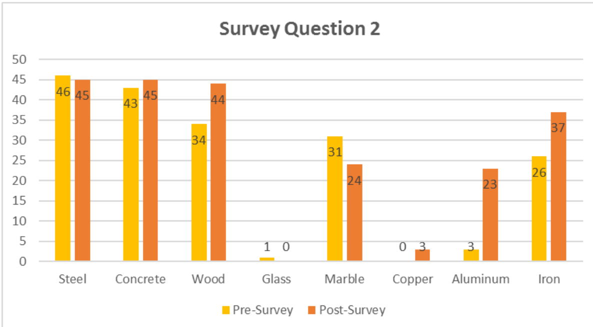


Figure 2: Students' answers to question two pre-survey and post-survey.

Question 3-Pre-Survey:

Tell us, from your experience, of a building/ bridge/ built environment project that caught you by surprise and you deemed it aesthetically beautiful. Do you recall if the structural system mattered in its inspiration? Why or why not?

A majority of students answered question 3 with descriptions of structures they have noticed prior to the presentation. Responses include awareness of height, comparison to nature and aesthetic beauty.

Question 3-Post Survey:

Tell us what you observed from your recent experience creating/ making a structures project in class. What fundamentals of structural design caught your attention and may influence your future designs?

Question 3 of the second survey resulted in higher structural responses. Students found structures interesting. Answers included awareness of column support, tension support, absorbing impact, and durability.

Question 4: On the next page is a familiar floor plan to your work this semester. Revisit this floor plan, however, this time with the structural system in mind. Thoughtfully, please mark where you believe:

a. Structural vertical supports (columns) are

b. Layout how you imagine the horizontal structural system (beams) run to hold up the roof membrane

Answers differ greatly within the student responses for column and beam placement in both the pre and post presentation surveys.

From the observations from the fall semester presentation, exercise, and surveys; in the short answer post survey questions, students showed some understanding of how a structure should perform. Many of the student's answers contained a short analysis of how the structural components keep the building standing during impact and/ or load increase. Students also realized that structures that seem to be designed well did not perform the best, structurally. Students also identified that structures using heavier material were not always the better designs. Lastly, they observed that lighter material was favorable for optimization and was more efficient.

This was concluded as a fairly successful workshop with structures introduction. Students gained new knowledge and some form of understanding structures with this first trial. This was apparent, as some of these observations were not reflected in their pre-structure presentation survey. It was clearly noticeable that many students were intrigued by how structures are inspired by nature and natural elements. Overall, some of the changes were not expected, this introductory lecture was effective, being such a short period of time that the material was introduced. Given that students maintained information after one class session and exercise, it can be deemed that earlier introduction of structural material is useful in student learning.

Workshop 2: 2018 Spring Semester Trial II

Following the research conducted in the fall semester on 45 first year students, a second round of structural systems was introduced in spring semester. The second round of implementation consisted of the same material introduced in the fall semester. This information was presented in PowerPoint format, and it included deeper descriptions of horizontal and lateral loads, material types and design examples in comparison to the fall presentation. This prior information was added as a refresher and as additional reinforcement. The newer information that was introduced consisted of lateral resisting load structural system; shear wall introduction, bracing types and delved deeper into the role of load bearing systems.

Structural Exercise Procedure

At the last part of the presentation, students were shown a 15-minute slide show to which they later utilized in their structural project. Following the PowerPoint presentation, the students were given a survey including six structural questions, four multiple choice and two short answer. Next, the students began their structural design task. The objective of the project was to create a structure that could bear a wind load and a live [human] load without failing. However, the structures were tested under simulated wind load.

The procedure consisted of splitting students into teams of 2-4. Using their current knowledge of structures, they were given thirty minutes to gather supplies and materials. The material used could not be heavy wood, steel, heavy metal, or strong bonding glue. Students were then given thirty minutes to design and construct their project. Dimensions could be no bigger than three feet wide, three feet tall, and three feet long. Students selected their own groups and a total of 10 designs were created. After testing the structures, the final survey was given to the students.

The following is image of the students constructing their structures (Figure 3).

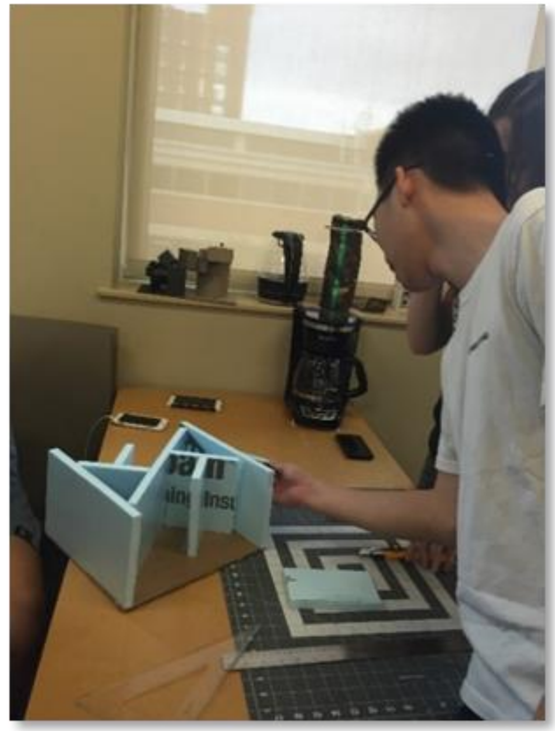


Figure 3: Students are working on their spring semester designs for part II of the research implementation.

Structural Design Results

Following completion of their designs, the testing of their structures ensued. First, the structures were placed on the floor with no attachments. Then, the wind blew from an inverted-vacuum to the structures. The heaver structures were shown more stability than the lighter ones as there were no attachments to the floor. Then, Mikey, a 205-pound student within the studio course appointed as the live load placed on top of each structure. In addition, two hand weights weighing 10 and 12 pounds were added to Mikey's weight during the testing. A total of 10 designs ranging from big to small were created. Many of the designs included bracing inside the structure; bracing was heavily emphasized throughout the second presentation that was shown to the students.

Of the 10 designs, three failed. These failures occurred from material choice, strength, and design. In this test, the lightest design also happened to be the strongest and sturdiest. The students who designed this structure exercised an understanding of bracing and the utilization of optimized materials. Safety precautions were taken in advance to ensure the student's safety when conducting the exercise.

Spring Pre and Post Survey Questions

Survey one and two both consisted of 6 questions; four multiple choice and two short answer. The questions and analysis are presented in the next section:

Question 1: What are structural systems in a building?

a. Beam
b. Partition
c. Column
d. Bracing
e. Ceiling
f. Shear wall
g. Mechanical pipes/ equipment
h. HVAC

Question 2: What do structural systems do in a building?

a. Supporting self-weight of building
b. Supporting wind loads
c. Supporting seismic loads
d. Supporting snow loads
e. For beauty of the building
f. Supporting mechanical and electrical loads
g. Supporting rain loads

Question 3: Do only complex buildings need structural systems?

a. Yes
b. No

Question 4: What are acceptable materials to use for column and beam construction?

a. Wood
b. Marble
c. Glass
d. Steel
e. Iron
f. Concrete
g. Copper

Spring Pre and Post Survey Analysis

Question 1: What are structural systems in a building?

In the survey completed prior to the structural activity, a high selection for beam, column, and bracing shown. HVAC systems received the least number of votes, with only 4 students selecting this as a structural system. This shows that students understand the difference between internal systems, and structural systems.

The survey conducted after the addition of more students to the class lecture. In comparison to question 1 from survey 1, beam, column and bracing still received the highest selections. The selection of shear wall went up by 21 votes, and mechanical pipes and HVAC selections decreased.

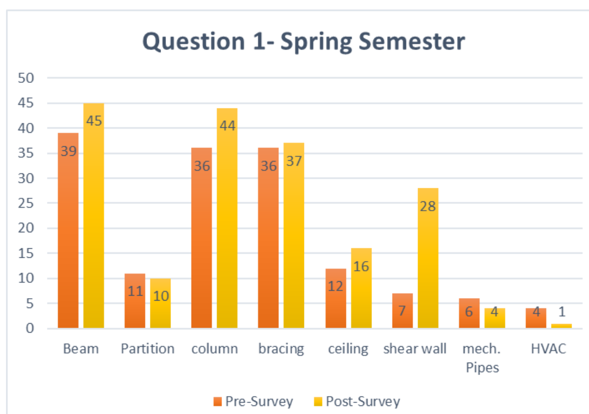


Figure 4 shows the results from pre-survey and post-survey.

Question 2: What do structural systems do in a building?

There was a high selection of self-weight, wind, seismic, snow, Mechanical pipes/equipment (ME) and rain loads in the first survey. The beauty of the building, choice E,

had only 13 selections. Students were shown structural systems that contributed to building aesthetics in the PowerPoint prior to the testing. With the results of question two from survey one; it seems most students still do not associate structural systems with beauty and aesthetics.

For question 2, all answers increased in selection with the second survey. Students retained the information from presentation 2 as well as the understanding that structures support the entirety of the design and its loads.

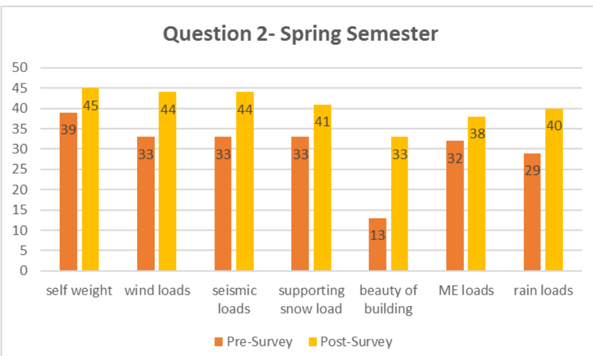


Figure 5 shows data for question 2 for pre-survey and post-survey.

Question 3: Do only complex buildings need structural systems?

-37 of the 39 responses properly assessed that complex buildings are not the only structures that need structural systems in the pre-survey.

The answers maintained nearly 100 percent of no votes, with only one student choosing yes in the survey after the workshop.

Question 4: What are acceptable materials to use for column and beam construction?

The pre-survey shows high selections for wood, steel, concrete, and iron when it comes to the selections for beam construction. Iron is not an acceptable material for this type of structural application; however, it seems students still associate all metals to be adequate for structural systems. Though iron had thirty-two votes, most students have not been able to distinguish the difference between iron and steel strength.

In survey two, the students' responses maintained a high selection of wood, steel, and concrete. Selections of iron and marble decreased while glass and copper had a slight increase. Some of the students have not yet associated certain strengths with materials not suitable for structures design.

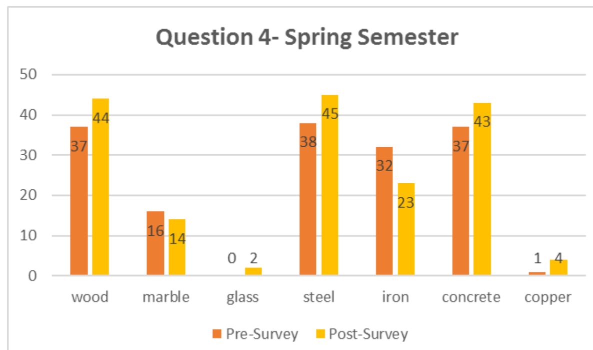
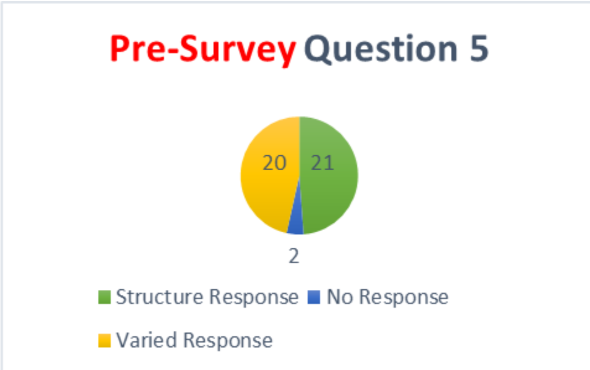
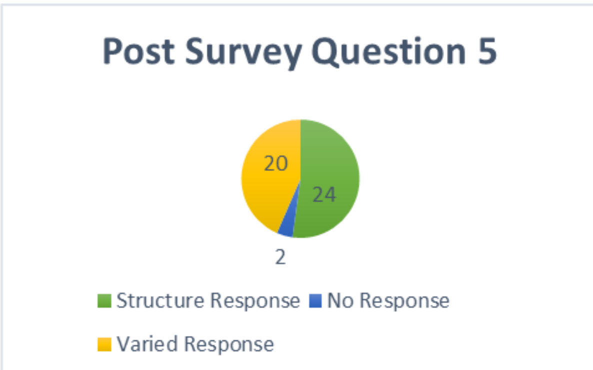


Figure 6: Students' answers to question four (left to right): pre-survey, and post-survey.

Question 5: What do you remember from last semester's introduction to structures course?

The answers varied. Nearly, half of the students answered with varied responses that showed a wide range of memory or lack thereof (this includes answers such as "a lot", "I'm not sure", "the egg drop", etc.). Over half of the students answered with a response that includes structures material/ terminology on both surveys.





Figures 7 & 8: Students' answers to question 5 pre-survey, and post-survey respectively.

Question 6 - Pre-Survey: What do you think you will learn from the structural activity you will complete today?

Nearly, half of the students answering with varied responses on what they anticipated to learn. Over half of the students answered with a response that includes structures material/terminology on survey 1.

Question 6 - Post Survey: What do you think you learned from the structural activity you will complete today?

After completing the lecture and activity, all students responded, with majority of students leaving a structure response.

Conclusions

The results were deemed effective, as students have retained much of the structural information presented to them in two lectures. The results from these lectures and tests proved to influence the students' knowledge and understanding of structures.

Many of the students have gained some type of structural understanding from these two workshops including lectures and activities. The activities provided the students with added reinforcement in understanding how these components work in design. With signs of improvement after activity completion, more sessions need to be conducted to see how much the students have actually retained.

Overall, the workshop method was a fairly successful structures introduction into architectural form. Likewise, the results prove integrating workshops and active-student learning techniques influence students' knowledge and understanding of structures.
However, further research is recommended to follow these freshmen students through their second year in the program. The study will examine if these same architect students: (1) retain and use structures in their designs - long before they actually take traditional structure curriculum coursework in their third year; and (2), if innovation with structural components appear in their work.

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