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Building Intuition for Moments - The Design of Moment Master, a Gamified Learning Tool for Engineering Statics

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Abstract:

Developing a robust understanding of the moment of a force remains a persistent challenge for students in introductory Statics. Learners frequently struggle to determine which force components generate rotation, identify appropriate moment arms in planar and spatial systems, and visualize how forces produce rotation about a specific point or an axis. These conceptual difficulties often propagate into advanced mechanics coursework, where an underdeveloped understanding of fundamental moment principles constrains students' ability to apply equilibrium equations and vector operations effectively.

Moment Master was developed to help address these challenges through an interactive, browser-based platform that scaffolds student engagement with moment concepts. The platform guides students through progressively complex, gamified levels ranging from basic two-dimensional moment calculations to fully three-dimensional moment problems. At each level, students select force vectors, distances, and compute resulting moments using a scalar formulation while receiving immediate, animated feedback that visually illustrates the corresponding rotation. This multimodal representation is intended to strengthen students' ability to interpret illustrative information and meaningfully connect mathematical operations with the underlying physical phenomena.

Moment Master is grounded in constructivist learning theory and research on the pedagogical value of multiple representations in engineering education. This acts as a digital manipulative tool where students use an online environment to actively interact with objects, forces, and spatial relationships rather than passively observe static diagrams. Its lightweight, web-native architecture allows flexible and self-paced exploration outside of the traditional classroom setting.

While formal classroom implementation and controlled evaluations are planned for future work, this paper focuses on the pedagogical motivation system architecture, and major design decisions underlying the tool. The discussion examines how interactive, game-based learning environments can augment traditional instruction in statics by fostering conceptual understanding, improving spatial reasoning, and supporting the development of transferable problem-solving skills in engineering.

Introduction:

Engineering Statics is consistently identified by students as one of the more demanding courses in the early engineering curriculum. Some of these challenges stem from insufficient preparation in prerequisite domains such as geometry, trigonometry, vector algebra, and foundational physics. Additional challenges arise from students' perceptions of Statics as disproportionately difficult relative to earlier engineering courses, particularly those in which grading curves may have mitigated performance concerns. These factors often appear to reduce students' motivation and self-efficacy, leading to fewer attempts at practice problems, reduced engagement with homework, and inadequate exam preparation; often driven by the belief that the subject matter is inherently too difficult to master.

Even when students persist despite gaps in background knowledge and fluctuating motivation, many continue to struggle with core conceptual elements central to Statics. Spatial visualization demands associated with three-dimensional (3D) problem solving, interpretation of support conditions, and understanding of moments and couples are among the most commonly reported areas of difficulty [1], [2]. As a result, students may spend much of the semester struggling with one or more of these concepts while simultaneously being introduced to new material.

Given these persistent conceptual challenges, particular attention is warranted for the moment of a force (torque), as it is a foundational concept that appears repeatedly throughout Statics. After students progress beyond concurrent force systems and are introduced to the moment of a force, nearly all subsequent topic in the course requires formulating at least one moment equilibrium equation. Within standard equilibrium-analysis procedures, writing the moment equation is often the first analytical step following construction of a free-body diagram, making its accuracy critical since most subsequent calculations depend directly on it. Despite the centrality of moment mechanics and the extensive repetition students encounter through rigid-body equilibrium problems, many continue to struggle with identifying appropriate moment arms, determining which force components contribute to rotation about a point or axis, and applying sign convention consistently when constructing complete and correct moment summation equations. This persistence of difficulty motivates the present study's focus on student understanding of the moment of a force.

A commonly proposed solution to help students understand Statics is increased exposure to practice problems; to become proficient at solving statics problems, students must solve statics problems. However, today's college students often have busy schedules in addition to required homework for Statics and other courses. When this is combined with potential motivational challenges and significant time spent on mobile devices, many students are either uninterested in or feel they lack the time to complete additional practice problems. As a result, there is a need for focused practice problems that still provide sufficient repetition for skill development. These problems should be simple enough to emphasize the learning objective at hand, yet complex enough to prevent rote memorization and instead promote a systematic problem-solving process. Given these constraints, students' extensive reliance on mobile devices suggests an opportunity: leveraging these platforms to deliver lightweight, web-based learning environments that provide targeted practice, sustained engagement, and the conceptual support traditional systems lack.

In response to these needs, many textbook publishers now provide online homework systems in which students solve problems, enter numerical answers, and receive immediate feedback on correctness. Although these systems can reinforce procedural fluency, they typically provide limited interaction beyond answer checking and often reproduce the same cognitive workflow as pencil-and-paper approaches, with only final answers being submitted and evaluated. As a result, these platforms may contribute little toward cultivating deeper conceptual understanding or sustaining student engagement.

To address the limitations of traditional online homework systems, researchers have explored a range of instructional approaches aimed at improving students' conceptual understanding of Statics, including the moment of a force. One commonly explored approach involves physical manipulatives and model-building activities designed to help students experience abstract mechanical concepts such as force, moment, and equilibrium. Prior work has shown that these hands-on approaches can increase student engagement and, in some cases, improve conceptual understanding by making rotational effects more tangible, though results are often mixed and context-dependent [3], [4], [5]. Related efforts have paired manipulatives with guided worksheets or structured activities that explicitly emphasize moment arms, rotational tendency, and equilibrium reasoning, promoting conceptual discussion beyond traditional lecture formats [6].

In addition to physical manipulatives, other research has focused on instructional strategies that support learning of moments through visualization, interaction, and scaffolded practice. Interactive simulations and virtual manipulatives have been shown to help students reason about torque by dynamically varying force magnitude, direction, and line of action while observing resulting rotational effects [7], [8]. Studies in both engineering and physics education have also highlighted the value of scaffolded problem sequences and multiple-representation approaches such as linking free-body diagrams, geometric reasoning, and symbolic expressions to improve student understanding of moments and equilibrium conditions [9], [10]. Additionally, formative feedback mechanisms that go beyond binary correct/incorrect responses have been shown to better support conceptual learning by helping students identify which forces and distances meaningfully contribute to a moment [2]. These works suggest that effective support for learning the moment of a force requires targeted practice environments that emphasize conceptual reasoning, visualization, and feedback, rather than reliance on numerical answer entry alone.

The present paper introduces *Moment Master,* a web-based learning environment designed to integrate several of the pedagogical features shown to support conceptual development in Statics. The application delivers tightly focused practice tasks that emphasize conceptual reasoning while minimizing extraneous computational demands. It offers immediate feedback on answer correctness and allows students to make multiple attempts without time-consuming rework. The tool is structured to build concepts gradually, reinforcing foundational ideas before progressing to more advanced problems in which the underlying principles remain consistent. In this way, *Moment Master* begins with simple, exploratory interactions similar to those found in interactive simulations such as PhET [8], but intentionally advances in difficulty to support deeper conceptualization and formal computation of the moment of a force, ultimately preparing students to solve higher-level Statics problems independently. While *Moment Master* shares similarities with digital and virtual manipulative tools, its primary focus is on supporting the structured formulation of moment calculations while building conceptual understanding.

This work is grounded primarily in constructivist learning theory, which emphasizes active student engagement and the development of understanding through interaction rather than passive reception. Within engineering education, constructivist approaches have been shown to be particularly effective when students are given structured opportunities to explore abstract concepts and make sense of them through multiple forms of representation, including visual diagrams, symbolic expressions, and physical or virtual manipulatives [7], [9], [10].

Principles of instructional scaffolding further inform the design of *Moment Master*. Scaffolded learning environments are intended to manage cognitive demands by providing support early in the learning process and then gradually increasing task complexity as understanding develops. Prior research in Statics and mechanics education suggests that scaffolded problem sequences and well-timed formative feedback can help students develop stronger conceptual foundations, especially for topics such as moments that require careful reasoning about geometry, force direction, and rotational effects [2], [7], [9].

Moment Master was designed to operationalize these theoretical principles through a structured, level-based digital environment. The tool emphasizes conceptual reasoning supported by visualization and immediate feedback, while intentionally minimizing extraneous computational load.

Moment Master Use in the Course:

Moment Master is designed to give students additional practice building fundamental concepts of moments. Students are expected to work through all 15 levels of *Moment Master* within the first two weeks of initial instruction on the moment of a force. The tool was intentionally designed to be completed in under two hours. This is currently offered as extra credit for students to complete and is therefore optional. *Moment Master* does not replace the computation and systematic process of written out homework sets but rather acts as supplemental problems that students can do outside of class. At the time of this paper, 150 students have used *Moment Master*. Data collection is ongoing, but preliminary results indicate an average completion time of 1.8 hours for all 15 levels. The remainder of this paper focuses on the intentional design choices underlying *Moment Master*.

Moment Master Design:

Moment Master was designed as a web-based application that is compatible across desktops, tablets, and phones. This approach was selected over a native phone application for two primary reasons. First, phone app development and deployment can be more time-consuming due to platform-specific approval processes and testing requirements, particularly when publishing to both the Apple App Store and Google Play. Additionally, data collection and tracking through native phone apps introduces additional layers of complexity. Second, desktop computers provide hover functionality via a cursor, which supports several key user-interface features within *Moment Master*. While the application functions on phones and tablets, users are prompted to switch to a desktop device for improved functionality and overall user experience.

The front end of *Moment Master* was built entirely on an HTML/CSS/JavaScript platform. All two-dimensional (2D) levels were coded as Scalable Vector Graphics (SVG) files, allowing metadata such as force locations and magnitudes, distances, and coordinate locations of points to be captured directly within the graphic. All three-dimensional (3D) levels were coded in

JavaScript using the Babylon.js library to render simple 3D bodies and similarly store metadata for forces, distances, and point coordinates. To introduce variation between students, 2D levels randomly select the point about which the moment is calculated, while 3D levels randomly vary force magnitudes within a specified range. The back end of *Moment Master* was developed using Google Firebase to manage user data, including account information, saved progress, and recorded responses.

The design of *Moment Master* emphasizes a scalar approach to calculating moments (M = Fd) rather than a vector approach (**M** = **r** x **F**). Although both methods are introduced and used within the Statics course, scalar analysis is typically emphasized more heavily in later topics. Additionally, scalar analysis encourages students to engage more directly with the conceptual meaning of a moment, particularly in 3D contexts, as it requires identifying the correct force components and perpendicular distances that contribute to rotational tendency about a specified axis. The sign convention used throughout *Moment Master* is based on the right-hand rule. In contrast, vector analysis allows students to compute a result once the position vector is defined, with limited need to reason about the physical interpretation or direction of the resulting moment.

Similar to other online Statics platforms such as Pearson's MyLab and Mastering, and McGraw Hill's Connect, *Moment Master* provides immediate feedback indicating whether a student's answer is correct or incorrect. If an answer is incorrect, the correct solution is not displayed; instead, the student is encouraged to retry the problem. Beyond this similarity, *Moment Master* differs from traditional online homework systems in three primary ways:

1. **Problems are broken into bite-sized components.** If an answer is incorrect, recalculating the response is not a long or tedious process and requires only a short amount of time. This design choice is intended to help maintain student engagement and encourage repeated attempts rather than disengagement or giving up.

2. **Calculations are minimized.** In most cases, calculations are performed automatically by the application after students select forces or distances directly from the figure. Selected values populate the input fields (Figure 1) and are used to compute the moment once force, distance, and direction are specified. Students may also manually enter values if preferred. This approach allows students to focus on the conceptual structure of the moment calculation rather than on arithmetic or trigonometric manipulation. The same principle applies to forces with multiple components, where students can hover over a force to select the appropriate component without explicitly performing trigonometric calculations (Figure 2).

3. **Visual feedback is provided following a correct response.** After a correct answer is submitted, an animation illustrates the rotational tendency produced by the applied force. For example, in Figure 1, the rotation animation would occur about point C and would rotate clockwise based on the problem prompt of the moment due to F_1. This visual feedback reinforces understanding of positive and negative moment conventions in both

2D and 3D contexts and helps students visualize the axis of rotation in three-dimensional problems.

The user interface of *Moment Master* was designed to be as simple as possible while still giving the user options for how they want to use the program. Instructions are displayed as popup messages before starting Level 1 and give all of the information necessary to complete the problems. Additionally, a help/tutorial video describes the functionality of *Moment Master* that can be found at the following link: https://moment-master.web.app/help.html

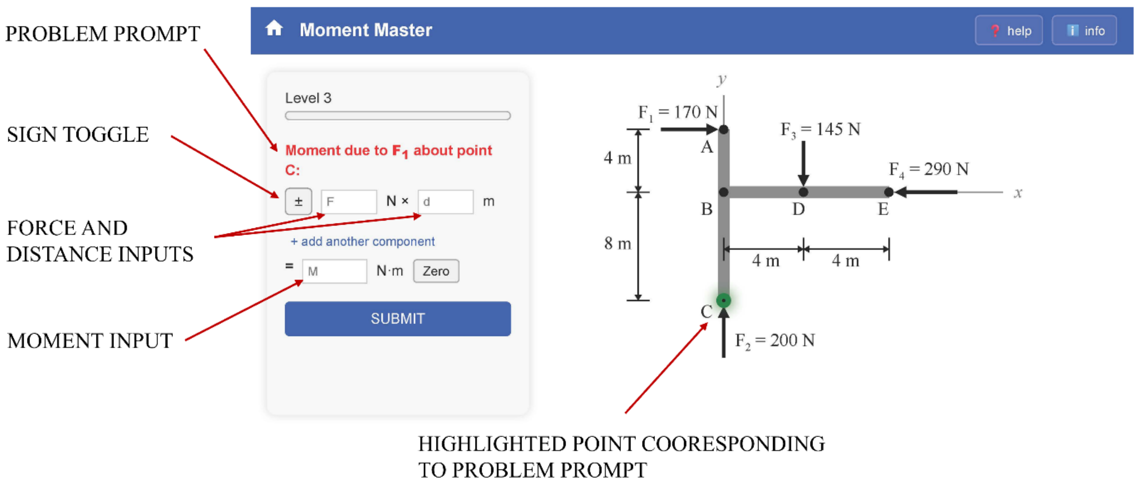

Figure 1. Moment Master Level 3 showing user interface

Figure 1 shows Level 3 of *Moment Master* as an illustrative example. Based on the prompt shown of determining the "Moment due to F_1 about point C:", the user has several available solution pathways:

- Manually calculate the moment and enter "-2040" into the moment input
- Type "170" into the force input, type "12" into the distance input, and toggle the sign of the moment to negative
- Click the 170 N force (either the label or the vector) which will auto populate its magnitude in the force input, toggle the sign of the moment to negative, then do one of the following options for the distance:
  - Type "4 + 8" or "12" in the distance input
  - Click point C and click point A. This will measure the distance between the points, show this measurement on the figure, and auto populate that distance of 12m in the distance input

The levels begin with very simple configurations and progressively increase in difficulty by introducing more complex geometry or scenarios in which multiple components of a force contribute to the moment. This structured progression is intentionally similar to a game-based design, in which difficulty increases incrementally across levels. Levels 1–10 are 2D, while

Levels 11–15 extend the same concepts into 3D problems. Each 2D level contains four applied forces, some of which may not contribute to the moment depending on the randomly selected point about which the moment is taken. Each successive level introduces a small additional learning objective, gradually building students' intuition for how forces create rotational effects. While all levels allow users to click on forces and distances, more advanced levels, such as Level 10 (Figure 3), require students to apply trigonometric reasoning to identify appropriate moment arms.

One potential concern with *Moment Master* is the limited need for explicit calculations. The reduction in required calculations was a deliberate design choice to provide a practice environment that is efficient and user-friendly while still requiring students to identify the correct physical inputs needed to compute a moment. The intent of the tool, however, is to reinforce conceptual understanding of moments and Statics principles rather than to function as a calculator that simply produces numerical answers. By allowing students to view force components through hover interactions rather than explicitly computing them, the tool encourages students to focus on *which* components contribute to rotational tendency and *why*. For example, Figure 2 presents a level with a skewed coordinate system, prompting students to reason about parallel and perpendicular force components rather than defaulting to traditional horizontal and vertical components. This perspective can simplify moment calculations, yet students may not naturally consider it without explicit visual support. Thus, even when students are not manually calculating distances or force components, meaningful learning is still expected to occur.

At higher levels, this scaffolding is gradually reduced. In Level 10 (Figure 3), students may still hover over forces to view components, but no points are aligned perfectly along horizontal or vertical directions to directly obtain perpendicular distances. As a result, students must apply the conceptual understanding developed in earlier levels to determine appropriate moment arms independently. This design makes Level 10 the most challenging 2D level, as reflected by longer completion times and a higher number of attempted solutions before success.

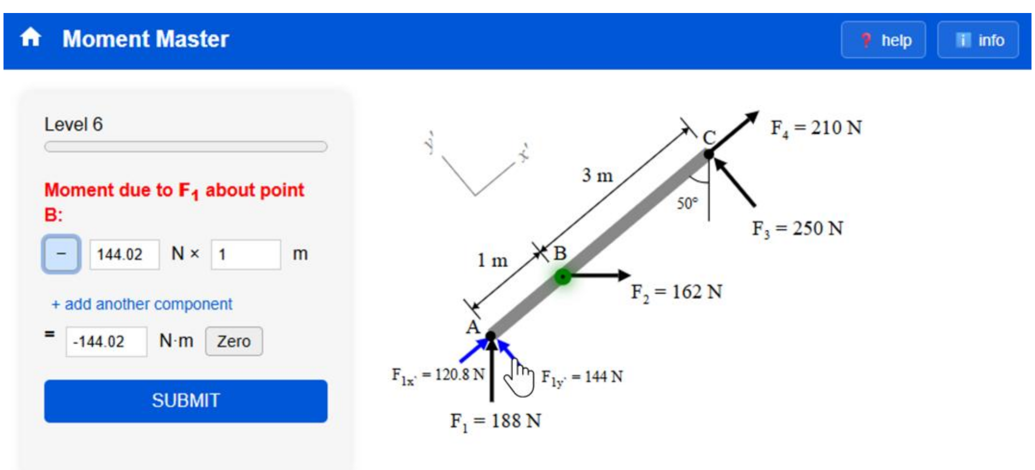

Figure 2. Moment Master Level 6 showing component-hover functionality

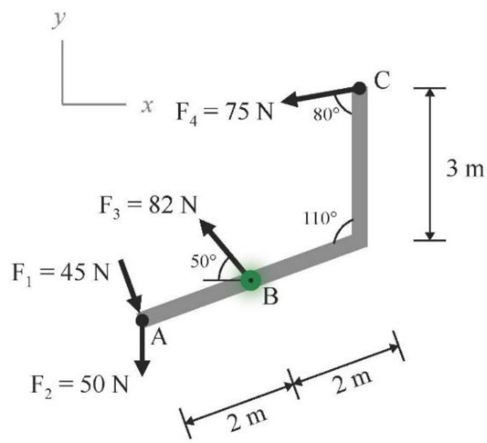

Figure 3. Moment Master Level 10

The prompt for each problem in the 3D levels changes slightly to ask for the moment that each force causes about a specific axis, rather than just a point. It then cycles through each force about each axis resulting in 15 total process steps in the case of Level 13 (Figure 4). These 3D levels retain the same click-based interface used in the 2D levels while also allowing users to rotate the model by clicking and dragging. This interaction enables students to view the problem from different orientations and observe that the moment of a force in 3D reduces conceptually to the same principles used in 2D when the axis of interest is viewed head-on. The final level of *Moment Master* (Figure 5) requires students to recognize multiple components of a force that can cause a moment about a single axis in 3D. These forces were given as Cartesian vectors so students do not have to calculate the vector components for the same reason mentioned in the 2D levels.

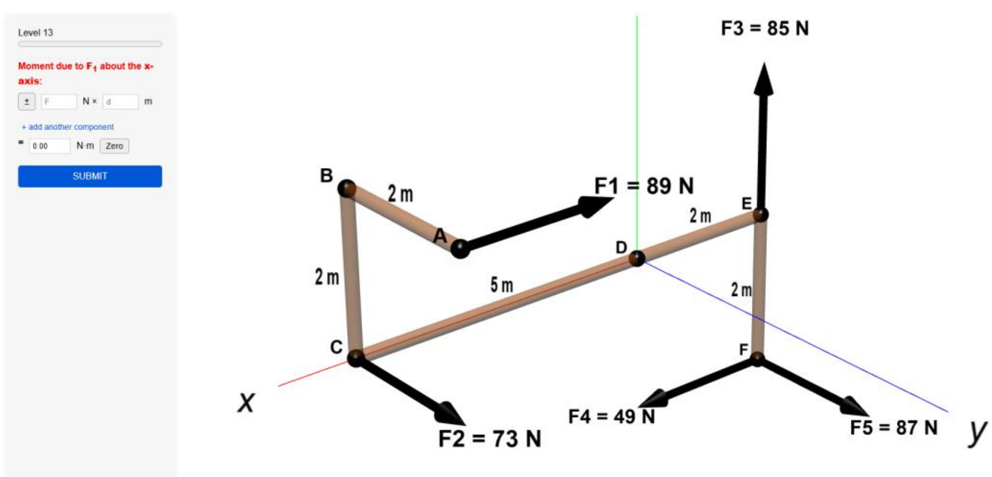

Figure 4. Moment Master Level 13 showing an example of a 3D level

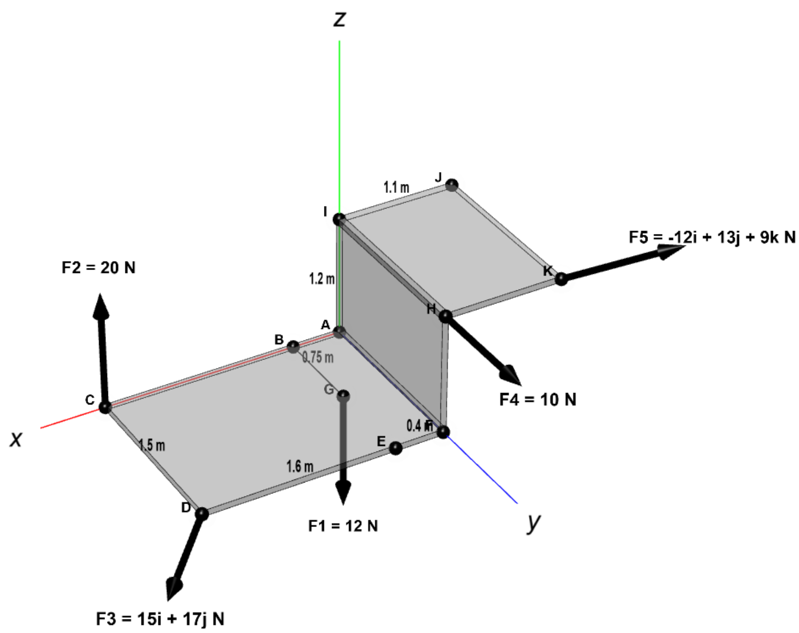

Figure 5. Moment Master Level 15

Discussion and Future Work:

The tool presented in this paper, *Moment Master*, offers students a structured way to practice the moment of a force using a level-based approach. In this framework, problems begin with simple configurations designed to build confidence and foundational understanding and gradually progress to more complex scenarios involving trigonometry and three-dimensional contexts.

This level-based structure aligns with prior research emphasizing scaffolded practice and gradual increases in complexity as effective means of supporting conceptual understanding in Statics. By isolating moment reasoning early and engaging students in a progression of increasingly complex contexts during initial instruction, *Moment Master* helps bridge the gap between exploratory visual tools and traditional equation-driven problem solving.

Future work will expand the feedback system beyond binary correctness by incorporating targeted, formative prompts based on common student errors. Prior research suggests that feedback which helps students identify *why* an answer is incorrect, rather than simply indicating incorrectness, can more effectively support conceptual learning. For example, after multiple unsuccessful attempts, hints could prompt students to reconsider moment arm selection, force components, or sign conventions, guiding them toward self-correction rather than solution revelation.

It is anticipated that extending this platform or applying a similar design approach to other topics within Statics will be valuable for strengthening students' conceptual foundations. This is particularly important for early Statics topics, where a strong understanding of fundamental concepts supports success in later coursework.

Ongoing data collection focuses on measures of conceptual understanding and problem-solving efficiency, with particular attention given to whether repeated interaction with moment-related problems improves students' ability to correctly formulate moment equilibrium equations. Data collection is still ongoing; however, preliminary findings are promising. At the time of this paper, https://moment-master.web.app/ is not configured for unrestricted free-play, as data collection is still in progress. Once this phase is complete, *Moment Master* will be made openly available for all students to practice and strengthen their understanding of the moment of a force.

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