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Bridging the Engineering Gap: The Impact of Scaffolded Mechanics Reviews in a Senior-Level Packaging Dynamics Course

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Abstract

Packaging is a STEM major that may be housed in engineering colleges (e.g., Rochester Institute of Technology) or agricultural colleges (e.g., Michigan State University), and packaging programs commonly hire faculty with engineering and science backgrounds to support technically rigorous curricula. In this context, XXX (Distribution Packaging Dynamics) is a senior-level undergraduate course in the School of YYY at AAA University (AAA) that prepares students for engineering-oriented roles in protective packaging design, packaging materials, and distribution systems. The course examines how mechanical and environmental hazards—including compression, shock, transportation vibration, temperature, altitude, and electrostatic effects—can influence packaged product integrity during distribution. Although students typically complete Calculus I–II, Physics I–II, and Statistics, many enter the course without a dedicated mechanics sequence (e.g., statics, mechanics of materials, dynamics, or vibration theory), which can create barriers when engaging with quantitative topics such as stress–strain interpretation, impact-energy reasoning for cushioning selection, and transportation vibration analysis. This Work-in-Progress paper presents a scaffolded prerequisite approach designed to help address this preparation gap by embedding short (10–20 minute) "engineering refresher" modules immediately before major course topics. These refreshers introduce essential engineering concepts in a just-in-time manner and link them directly to packaging applications and test methods. In addition to conceptual support, the approach incorporates structured onboarding of computational tools (e.g., MATLAB) to reduce the initial learning barrier and support basic analysis tasks such as plotting and data interpretation. Student survey feedback is used to highlight perceived challenges, as well as instructional strategies that may support student engagement and understanding. Overall, this work explores a practical instructional approach for supporting student learning in interdisciplinary STEM courses where engineering fundamentals must be applied within domain-specific contexts.

Introduction

Packaging is an interdisciplinary STEM field that integrates engineering, materials science, chemistry, food science, supply chain management, and design to protect products throughout the distribution environment. Packaging programs are offered in a variety of institutional contexts, including engineering colleges (e.g., Rochester Institute of Technology) and agricultural colleges (e.g., Michigan State University), with faculty often drawn from engineering, science, and technical backgrounds to support rigorous, applied curricula. A core component of these programs is Distribution Packaging Dynamics, a senior-level undergraduate engineering course (XXX at YYY) that prepares students to analyze how mechanical and environmental hazards—such as compression (e.g., squeezing of a corrugated box under stacking loads), shock (e.g., repeated drops during manual handling), transportation vibration, temperature (e.g., shipping a package from cold Michigan to hot Florida), and altitude (e.g., reduced external pressure at higher-altitude locations such as Denver, which can cause a potato chip bag to expand or burst)—affect packaged product performance.

Although packaging students typically complete foundational courses in calculus, physics, and statistics, many do not complete a dedicated mechanics sequence (e.g., statics, mechanics of materials, dynamics, or vibration theory) prior to taking Packaging Dynamics. This imbalance creates a preparation gap when students encounter the quantitative and conceptual demands inherent in topics such as stress–strain response, impact energy reasoning for cushioning selection, PSD-based vibration analysis, and heat transfer effects on cold-chain packaging. In addition to conceptual challenges, students may also face practical difficulties in using computational tools required for modern engineering analysis, including solving equations, generating plots, and interpreting transportation vibration data. As a result, Packaging Dynamics can become a course in which students must simultaneously learn new packaging content while developing prerequisite engineering and computational skills.

A well-established approach to addressing such learning barriers is instructional scaffolding [1], an educational strategy in which instructors provide structured support to help learners bridge the gap between their current understanding and the demands of new content. Scaffolding is grounded in cognitive and developmental theory, including the Zone of Proximal Development [2], where targeted support enables learners to accomplish tasks they would not complete independently, with guidance gradually reduced as competence develops. Wood et al. [3] further described how structured support from a more knowledgeable other enables learners to complete tasks beyond their unguided capacity. This approach aligns with theories suggesting that carefully sequenced instructional supports can reduce cognitive load and help learners progress toward more complex conceptual understanding [4]. Scaffolding has been applied across STEM education settings, demonstrating benefits for student engagement, conceptual development, and skill acquisition [1].

In the context of Packaging Dynamics, prerequisite engineering concepts such as basic mechanics, vibration response, heat transfer, and gas laws serve as important building blocks for deeper understanding. However, students often encounter these concepts for the first time within the XXX course, which can lead to reduced confidence and surface-level engagement with the material. To help address this need, the instructor implemented a scaffolded prerequisite approach that embeds short, targeted “engineering refresher” modules immediately before major course topics, linking prerequisite concepts to packaging applications and test methods. The approach also includes structured onboarding for computational tools (e.g., MATLAB) to reduce initial learning barriers and support basic analysis tasks.

This Work-in-Progress paper presents the design and early implementation of this scaffolded prerequisite approach, with student feedback used to inform ongoing course refinement. Survey responses highlight perceived challenges, the role of relevance in student motivation, and the value of structured instructional supports. While this study does not make causal claims about learning outcomes, it explores an instructional approach for supporting student engagement with engineering concepts in an interdisciplinary packaging context. To the authors’ knowledge, this work represents an early effort to explore and document the use of prerequisite scaffolding within packaging education.

Instructional Challenge: Engineering Prerequisites Embedded in Packaging Dynamics

XXX (Distribution Packaging Dynamics) is a senior-level undergraduate course in the Packaging major at YYY University. The course requires students to interpret distribution hazards using engineering representations and quantitative reasoning that many packaging students have not formally encountered prior to enrollment (Table 1). Although students typically complete Calculus I–II, Physics I–II, and Statistics, the lack of a dedicated mechanics sequence (e.g., statics, mechanics of materials, dynamics, or vibration theory) creates barriers when the course introduces tools commonly used in packaging design and testing. These include box compression force–displacement behavior and interpretation, cushioning performance curves (acceleration in G versus static stress), vibration characterization using power spectral density (PSD), G_{rms}, and resonance, heat transfer and phase-change concepts used in cold-chain packaging, gas-law reasoning for altitude-related package bloating, and electrostatic discharge (ESD) material classifications based on resistivity ranges.

Table 1. Student academic background prior to XXX course, highlighting the mechanics preparation gap.

Completed before XXX	Often not completed before XXX
Calculus I–II	Statics
Physics I–II	Mechanics of Materials
Statistics	Dynamics / Vibrations

In addition to conceptual prerequisites, Packaging Dynamics increasingly requires computational skills for solving problems, plotting results, and performing basic analysis of noisy transportation vibration data. Many packaging students have limited experience using engineering computation tools such as MATLAB (available to MSU students) and may initially perceive such software as primarily relevant to computer science rather than engineering analysis. However, computational proficiency is valuable in technical packaging roles, particularly in research and development settings and graduate-level work. To support this need, the instructor integrates MATLAB-based examples (e.g., solving selected homework problems, visualizing trends, and interpreting vibration representations) to familiarize students with computational workflows used in engineering practice.

To address the mechanics preparation gap, the instructor also embeds short prerequisite refreshers immediately before major course topics. For example, in the shock and impact module, students review basic kinematics and energy methods (e.g., estimating impact velocity from drop height and relating kinetic energy to simplified spring deformation) before applying these ideas to cushioning selection and package protection decisions. The course also emphasizes the limitations of simplified models and introduces how real cushioning materials may exhibit nonlinear and viscoelastic behavior in advanced applications [5]. Collectively, these challenges motivate the scaffolded prerequisite approach presented in this Work-in-Progress paper.

Scaffolded Prerequisite Approach

The proposed scaffolded prerequisite approach integrates short "engineering refresher" modules before each major Packaging Dynamics topic to provide the minimum essential engineering foundations needed for students to engage with the technical content. These refreshers are intentionally brief (approximately 10–20 minutes) and are introduced immediately prior to their application in the course. Rather than presenting full theoretical treatments, the approach focuses on targeted concepts that are directly relevant to the task at hand. Each refresher is followed by a packaging-specific example or activity, allowing students to apply the concepts in context. This just-in-time structure is intended to support connections between prerequisite engineering concepts and packaging applications while facilitating a smoother transition into more complex analysis and design tasks.

Implementation Example

<u>Dynamics and Impact Analysis (shock)</u>

During handling and distribution, a package may be dropped multiple times, potentially causing product damage. To support the shock module in XXX, students first review basic kinematics to estimate the impact velocity immediately before contact. Assuming free fall from a drop height H, the impact velocity is approximated as [6]:

$$v = \sqrt{2gH} \tag{1}$$

where g is gravitational acceleration and H is drop height. This refresher helps students connect a distribution scenario (drop height) to a measurable dynamic input (impact velocity), which is later linked to cushioning performance and fragility concerns. Students then review energy methods to estimate the deformation demand placed on the cushioning material during impact. The impact kinetic energy of the package is computed as:

$$KE = \frac{1}{2}mv^2 \tag{2}$$

where m is the package mass and v is the impact velocity. To translate this energy into a packaging design parameter (cushion thickness), the cushioning system is initially modeled as an equivalent linear spring with stiffness k. The spring potential energy stored during compression is:

$$PE = \frac{1}{2}kx^2 \tag{3}$$

where x is the cushioning deformation. By equating kinetic energy to spring potential energy ($KE = PE$), students obtain a first-order estimate of the deformation:

$$x = v\sqrt{\frac{m}{k}} \tag{4}$$

This simplified calculation allows students to evaluate whether the predicted deformation exceeds the available cushioning thickness. If x is greater than the foam thickness, the model suggests a bottoming-out risk, motivating either thicker cushioning, a different cushioning material (higher stiffness), or a design change that reduces drop height exposure. In class, this process is presented as a rapid engineering estimate that supports decision-making rather than a complete representation of impact physics. To connect the refresher to packaging testing practice, students are then introduced to how cushioning behavior is evaluated experimentally and represented through cushioning curves (e.g., peak acceleration in Gversus static stress). The instructor emphasizes that the spring approximation assumes a linear force–displacement response, whereas real cushioning foams typically exhibit nonlinear stress–strain behavior, rate sensitivity, and hysteresis. Therefore, while Eq. (4) provides an accessible starting point, it does not fully capture real packaging responses such as nonlinear compression, energy dissipation, or repeated-impact degradation. To "unhide" real-world complexity, students are shown how advanced research models cushioning materials as nonlinear hyperelastic and viscoelastic systems [5], which better represent foam response under dynamic loading.

Overall, this implementation example demonstrates how the scaffolded prerequisite approach supports students in building a bridge between fundamental mechanics (kinematics and energy methods) and packaging-specific design reasoning (cushion thickness selection, bottoming-out risk, and interpretation of cushioning test data).

<u>Computational Software: MATLAB</u>
A recurring barrier in XXX is not only limited prior exposure to computational tools, but also student hesitation to "start," which often reflects low self-efficacy and anxiety toward coding-oriented tasks. Many packaging students perceive MATLAB as unfamiliar or primarily relevant to computer science, creating a high entry threshold even for basic engineering computations.

To reduce this start-up barrier, the instructor uses a structured onboarding scaffold. Students first complete a short external tutorial (e.g., YouTube) along with instructor-recorded "baby-step" videos demonstrating MATLAB Online access, variable definitions, simple calculations, and plotting. In class, the instructor guides students through signing into MATLAB Online and completing a short, low-stakes activity (e.g., computing a value and generating a plot). This guided practice helps students overcome the initial learning-start obstacle and builds confidence early.

Early Evidence from Course Surveys

A survey was administered to XXX students in Fall 2024 to assess their experiences with MATLAB. A total of 74–77 students responded to each item. Figure 1 summarizes student responses (Disagree/Maybe/Agree) to three motivation-related statements about learning MATLAB. Overall, most students selected "Agree," indicating that motivation increases when MATLAB is presented as relevant to packaging industry applications, advanced technical roles (e.g., R&D or simulation), and future job advantages. The third statement (career advantage) received the strongest agreement, suggesting that perceived career value is a key driver for student engagement with computational tools.

■ (purple)	If I see the application of MATLAB in the packaging industry, I will be more interested in learning it
■ (orange)	Knowing that MATLAB is used in advanced packaging roles (e.g., R&D or simulations) motivates me to learn it.
■ (cyan)	If I understand how MATLAB skills give me an advantage in future job opportunities, I would invest more effort in learning it.

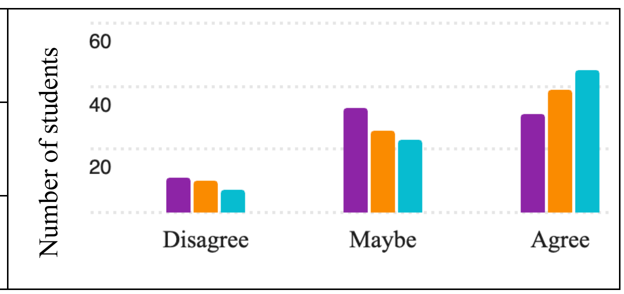
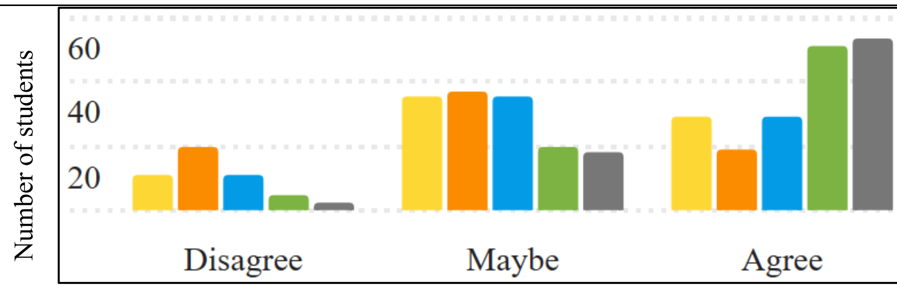


Figure 1. Students' responses on factors that increase motivation to learn MATLAB in XXX.

Figure 2 summarizes student responses regarding instructional strategies used to scaffold MATLAB learning in XXX. Overall, the results suggest that students were most supportive of structured, low-barrier entry supports, particularly step-by-step tutorials/videos and having dedicated in-class time to work collaboratively on MATLAB tasks, both of which received the strongest agreement. Application-driven activities (e.g., MATLAB problems tied to real packaging scenarios) and exposure to MATLAB use in packaging research through peer research-review presentations also showed positive trends, indicating that relevance and authentic examples help students recognize the value of computational tools. Collectively, these responses highlight that both guided onboarding and packaging-specific contextualization are important for improving student engagement with MATLAB.



- The instructor's explanation of how learning MATLAB can help packaging graduates stand out and prevent packaging jobs from being given to engineering graduates due to a lack of computational skills could somewhat convince me that learning MATLAB is beneficial.
- It was interesting and motivating when the instructor assigned a MATLAB problem to plot the trajectory of a package throw, as it was related to real packaging problems.
- When I learned that MATLAB has been used in packaging research through a research review presentation by my classmates, I could better see the value of learning it.
- Step-by-step tutorials and videos from the instructor could make MATLAB more approachable.
- Having in-class time, facilitated by the instructor, to work collaboratively on MATLAB assignments could help me learn better.

Figure 2. Students' responses on instructional strategies used to scaffold MATLAB learning in XXX.

Limitations

This Work-in-Progress paper has several limitations that should be considered when interpreting the findings. First, the current evidence is primarily based on student survey responses, which reflect perceptions and self-reported experiences rather than direct measures of learning. Second, the results represent a single course implementation within one institution and one academic context, which may limit generalizability to other programs or student populations. Third, while the scaffolded prerequisite approach is motivated by common learning barriers in XXX, the present study does not yet include a direct concept assessment (e.g., pre/post concept test) to quantify gains in mechanics understanding or problem-solving performance.

Conclusion

Packaging Dynamics is a senior-level interdisciplinary engineering course that requires students to interpret mechanical and environmental hazards using engineering representations and test methods. However, many packaging students enter the course without a dedicated mechanics sequence, creating barriers when concepts such as stress–strain interpretation, impact response, transportation vibration analysis, heat transfer, and altitude-related pressure effects are introduced. This Work-in-Progress paper described a scaffolded prerequisite approach that embeds short, just-in-time engineering refreshers prior to major course topics and links foundational concepts to packaging-specific applications. Early evidence from course surveys suggests that students value structured instructional supports and strategies that reduce initial barriers to engaging with technical content, including computational tools such as MATLAB. These responses suggest that targeted prerequisite refreshers may help students better connect engineering fundamentals to packaging applications and improve their engagement with course material. Overall, the approach highlights a practical pathway for supporting student learning in interdisciplinary STEM courses where engineering fundamentals must be applied in domain-specific contexts. Future work will focus on more rigorous assessment of student learning outcomes and confidence.

References

[1] B. R. Belland, *Instructional Scaffolding in STEM Education: Strategies and Efficacy Evidence*. Springer Nature, 2017.
[2] R. Wass and C. Golding, “Sharpening a tool for teaching: the zone of proximal development,” *Teaching in Higher Education*, vol. 19, no. 6, pp. 671–684, 2014.
[3] D. Wood, J. S. Bruner, and G. Ross, “The role of tutoring in problem solving,” *Journal of Child Psychology and Psychiatry*, vol. 17, no. 2, pp. 89–100, 1976.
[4] B. R. Belland, C. Kim, and M. J. Hannafin, “A framework for designing scaffolds that improve motivation and cognition,” *Educational Psychologist*, vol. 48, no. 4, pp. 243–270, 2013.
[5] A. Joodaky, G. S. Batt, and J. M. Gibert, “Prediction of cushion curves of polymer foams using a nonlinear distributed parameter model,” *Packaging Technology and Science*, vol. 33, no. 1, pp. 3–14, 2020.
[6] J. L. Meriam, L. G. Kraige, and J. N. Bolton, *Engineering Mechanics: Dynamics*. Hoboken, NJ, USA: Wiley, 2020.