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# The Format and Pedagogical Assessment of Integrating Explicit Dynamic Structural Analysis in an Undergraduate Finite Element Method Course

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## 1. Introduction

Recent advances in computational efficiency and robustness of explicit solvers within finite element analysis (FEA) software have made impact and high-rate transient analyses increasingly important in engineering applications where safety, durability, and extreme loading conditions are critical. Explicit dynamics methods are widely employed in automotive crashworthiness analysis [1, 2], head-impact modeling and sports safety equipment design [3, 4], bird strikes on aerospace turbine components, ballistic and penetration simulations [5, 6], armored vehicle development [7], and drop-testing of consumer electronic devices. Unlike implicit formulations, explicit dynamics solvers naturally capture inertia effects, high strain-rate material behavior, and complex contact interactions, enabling accurate representation of transient physical events occurring over millisecond time scales.

The growing industrial reliance on impact analysis, combined with the needs of multidisciplinary student design teams such as SAE Baja, Formula SAE, and Autonomous Vehicle, motivated the integration of a dedicated impact analysis module into an undergraduate Finite Element Analysis course. ANSYS LS-DYNA (Ansys Inc., Canonsburg, PA) [8] was selected as the primary instructional platform due to its widespread industrial adoption and its established capability for modeling short-duration, highly nonlinear transient events.

Traditional FEA instruction typically emphasizes static or quasi-static linear analyses; however, effective use of explicit solvers requires a fundamental shift in how students conceptualize numerical simulation. Students must develop an understanding of conditionally stable time integration, the role of time-step size in solution stability, appropriate application of mass scaling, and interpretation of energy balance as an indicator of solution quality. Although prior work has examined pedagogical approaches for teaching undergraduate finite element analysis [9-11], comparatively little literature addresses the instructional challenges associated with integrating explicit dynamics and impact analysis into the FEA curriculum. This paper seeks to address this gap by describing the design, implementation, and assessment of an explicit dynamics instructional module at the undergraduate level.

To complement the computational component, the authors developed a low-cost, portable drop-weight impact testing apparatus that provides a physical reference for the simulated results. This enables students to conduct controlled impact tests, measure deformation and structural response using imaging techniques, and directly compare experimental observations with corresponding LS-DYNA simulations. By integrating analytical concepts, numerical modeling, and experimental evidence, this dual-track instructional approach promotes deeper conceptual understanding of impact mechanics and reinforces awareness of the assumptions and limitations inherent in numerical simulation.

This paper presents the development and assessment of a teaching module that integrates impact experimentation and explicit dynamic simulation within an undergraduate finite element analysis course. The learning objectives of the module are to:

1. Introduce students to the fundamental concepts of explicit dynamics and impact analysis;
2. Provide hands-on experience using LS-DYNA to model and solve impact problems; and
3. Develop students' ability to synthesize theoretical knowledge, computational results, and experimental data.

## 2. Teaching Module Development and Implementation

The development of the instructional module was reported in the authors' prior work [12]. The present study focuses on the implementation of the module, including the delivery of theoretical background, hands-on LS-DYNA tutorials, and simulation of an associated experimental activity. In addition, the effectiveness of the instructional activities was evaluated using pre- and post-activity surveys.

### 2.1 Teaching Module Overview

The teaching module is implemented over two 80-minute class periods, structured as follows.

***First 80-minute class period:***
The first class period focuses on introducing the theoretical foundations of impact analysis and training students in the use of the LS-DYNA software. The session begins with a lecture covering fundamental concepts in explicit dynamics, impact mechanics, and relevant finite element modeling techniques. This is followed by an interactive, guided tutorial in which students complete a step-by-step simulation of a smartphone drop test using LS-DYNA. This activity is designed to provide students with hands-on experience and to reinforce the connection between theoretical concepts and computational implementation.

***Second 80-minute class period:***
The second class period emphasizes application and synthesis of the knowledge and skills developed in the first session. Students observe a controlled drop-weight impact experiment using a portable impact tester, during which deformation and response data are collected. Students then model and simulate the same experiment using LS-DYNA. The module culminates in a written discussion and analysis report, in which students critically examine and compare experimental observations with simulation results, reflecting on sources of discrepancy and the limitations of numerical modeling.

### 2.2 Implementation

The instructional module was implemented in three sections of the undergraduate Finite Element Analysis course during the Fall 2025 semester, with a total enrollment of 85 students. The module was scheduled during the latter portion of the semester, after students had learned fundamental finite element method (FEM) concepts and had participated in several weeks of hands-on ANSYS-based learning activities focused on static structural analysis.

### *First 80-Minute Class*

Learning activities during the first class period consisted of a lecture followed by guided, in-class exercises. The lecture component began with a brief review of impact analysis concepts, including the impact factor, previously covered in the Mechanical Design Analysis course [13]. The application of the finite element method to structural dynamics was then introduced through the derivation of governing equations for bar elements subjected to time-dependent loading. Two numerical solution approaches were discussed: the Central Difference method (explicit time integration) and Newmark's method (implicit time integration), with emphasis on their respective characteristics and applicability to impact problems.

Following the lecture, an interactive session was conducted in which students completed a step-by-step tutorial of a smartphone drop impact problem using ANSYS LS-DYNA. The problem was framed as follows.

> *Smartphones are frequently subjected to accidental drops during daily use, making impact resistance an important design consideration. Such events involve short-duration, highly nonlinear contact interactions and are well suited for analysis using explicit finite element methods. Students were asked to consider the vertical drop of a simplified smartphone model onto a rigid support surface from a height of 1.0 m and to use ANSYS LS-DYNA to determine the transient deformation and equivalent (von Mises) stress developed during the impact event.*
>
> *The parameters provided for the simulation included an explicit dynamics analysis formulation, a drop height of 1.0 m, a simplified aluminum alloy representation for the phone, a 3-mm-thick PLA impact surface, a friction coefficient of 0.6, and a total simulation time of 0.1 s.*

Figures 1–2 illustrate key preprocessing steps in LS-DYNA, including the specification of contact friction parameters, conditions corresponding to drop height, analysis end time, and the application of standard Earth gravity. Representative results for total deformation and equivalent stress are shown in Figure 3.

To reinforce the connection between analytical methods and numerical simulation, students subsequently completed an assignment requiring them to calculate the maximum deflection of a spherical ball impacting a slender, fixed-supported beam. This problem was solved using both the impact factor method and ANSYS LS-DYNA. Figure 4 presents the LS-DYNA model developed for this exercise.

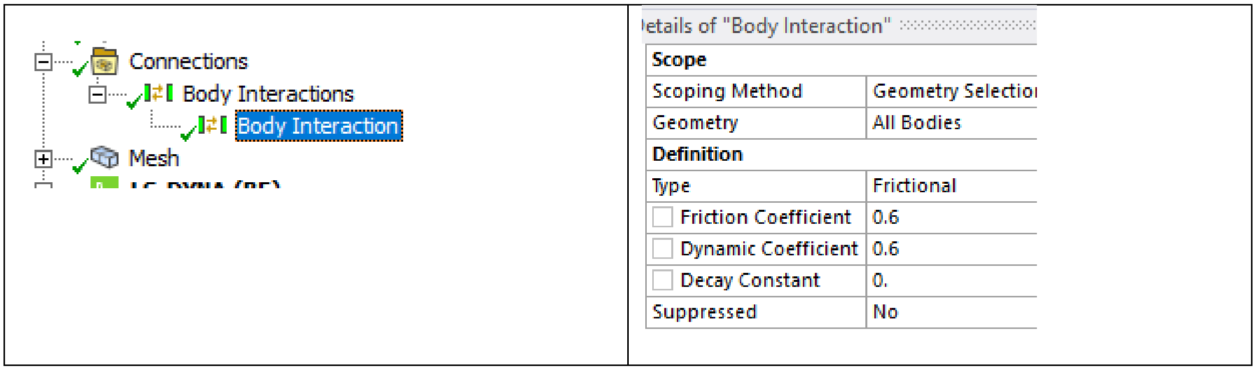


Figure 1. Set friction coefficient and dynamics coefficient

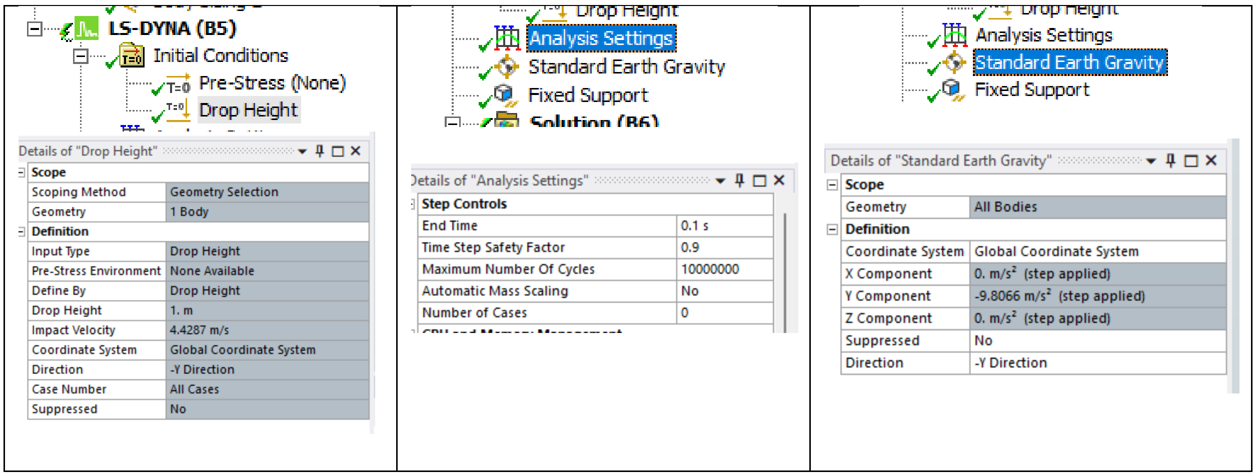


Figure 2. Analysis settings to specify Drop Height, End Time, and Standard Earth Gravity

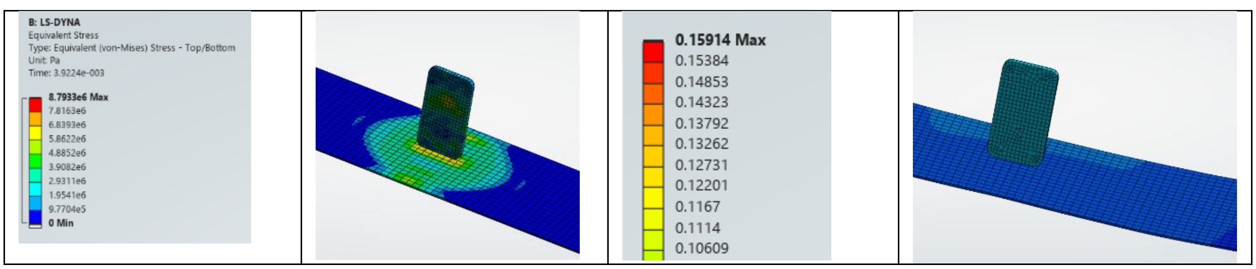


Figure 3. Example results: Stress and Deformation

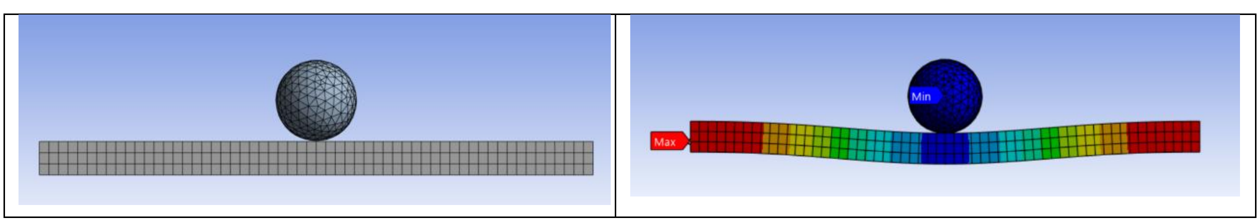


Figure 4. First class assignment: a) LS-DYNA model and b) deformed shape at t=0.006s

***Second 80-minute class***

During the second class period, the instructor introduced the drop-weight impact experiment by describing the experimental setup and presenting a recorded video of the testing and data collection process. Students then applied the knowledge and skills acquired during the first session to model and simulate the same drop-weight impact test using ANSYS LS-DYNA. Emphasis was placed on critical examination of both experimental and computational results and on comparing observed responses with simulation predictions.

The experiment was conducted using a portable, drop-weight–based impact tester, shown in Figure 5(a). The apparatus consists of three primary components: a specimen clamping system, a height-adjustable guide tube, and interchangeable drop strikers. Figure 5(b) illustrates the three striker geometries: semi-spherical, flat, and conical. To enable visualization of the impact event, a video recording system was incorporated into the tester, as shown in Figure 5(c).


Figure 5: a) Impact Tester, b) Strikers, and c) Video Recording Systems with Two Cameras [14]

For the recorded experiment used in this module, a semi-spherical striker was selected. The striker parameters are: 2lbs weight, a hemispherical tip diameter of 0.625 in, and an overall length of 5.5 in. The drop height was 8.5 in. The test specimen was a polycarbonate beam with dimensions of 1/16 in × 4.5 in × 1.75 in. The impact event was recorded at 120 frames per second (fps). The recorded video was subsequently converted into individual frames using a MATLAB script. A representative sequence of frames at selected time instants is shown in Figure 6, and the measured maximum deflection as a function of time is plotted in Figure 7. Deflection measurements were obtained using the image-processing software ImageJ. (ImageJ, U.S. National Institutes of Health, Bethesda, MD, USA).

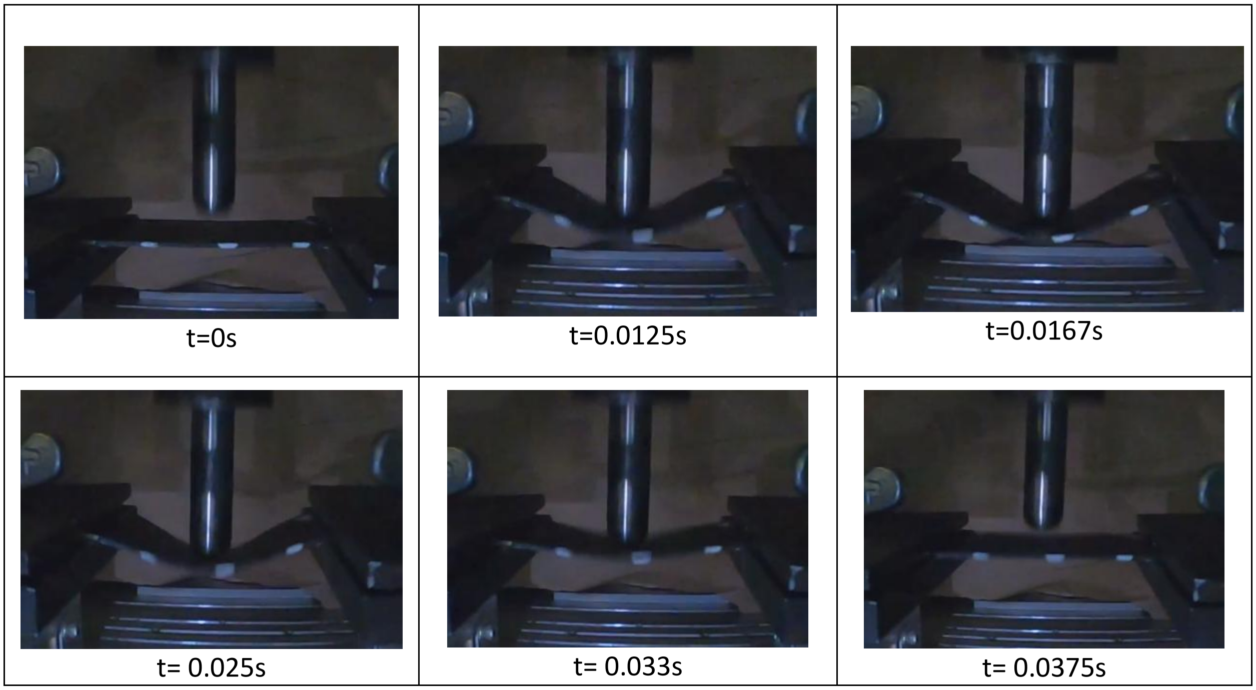


Figure 6. Frames converted from the recorded video at selected time points.

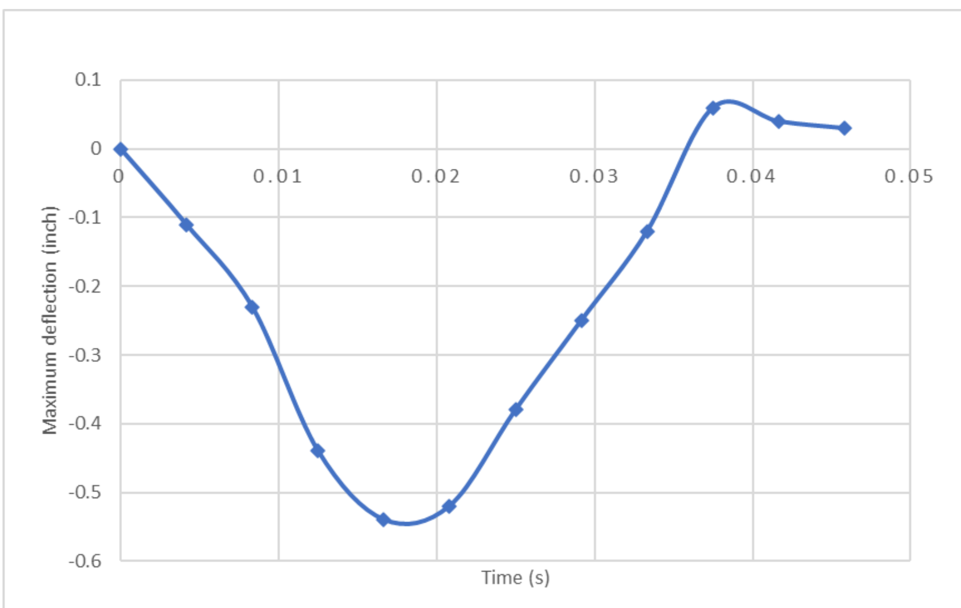


Figure 7. Maximum deflection of the specimen as a function of time

Based on the experimental configuration and loading conditions, students developed a corresponding finite element model in ANSYS LS-DYNA (Figure 8). This model was used to simulate the drop-weight impact and to compare predicted deflections with experimental measurements. Figure 9 presents a sequence of downward deflections from simulation. The deflection vs. time plot is shown in Figure 10. The same trends are observed in the experimental data and the simulation results.

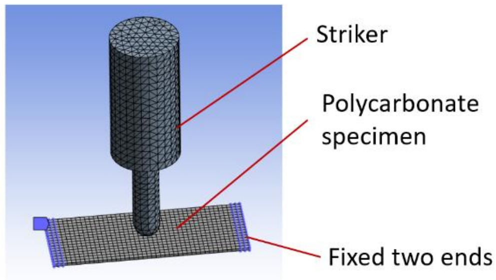


Figure 8. The finite element model created for the drop weight impact experiment.

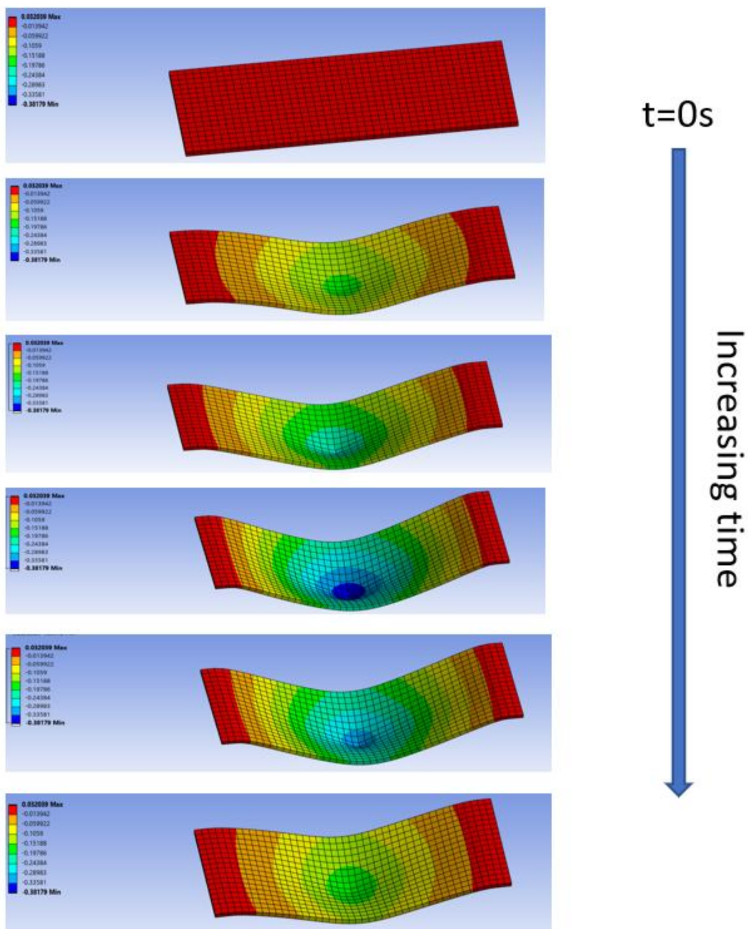


Figure 9. Deflection results from LS-DYNA at selected time points

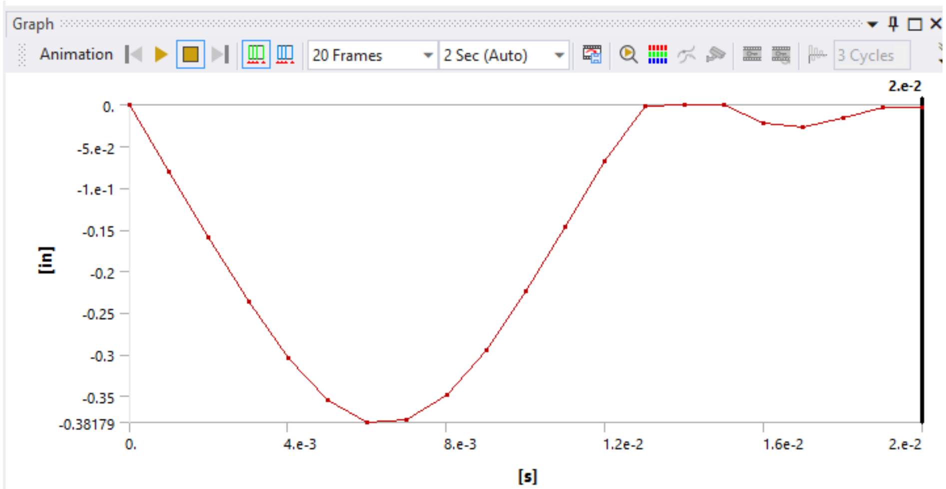


Figure 10. The deflection vs. time plot from LS-DYNA

## 3. Assessment Results and Analysis

Pre- and post-activity surveys were developed and administered to evaluate the effectiveness of the instructional strategy employed in the teaching module. The pre-activity survey assessed students' prior knowledge, familiarity with impact analysis concepts, and perceptions of the relevance and applications of impact analysis in engineering practice. The post-activity survey prompted students to reflect on the knowledge gained, skill development, and overall learning experience associated with the module. Detailed questions of the pre and post surveys are included in the Appendix.

Both quantitative and qualitative data were collected. Quantitative responses were measured using a 5-point Likert scale, ranging from *Extremely* to *Not at all*. Comparisons between pre- and post-activity survey results were used to evaluate changes in student understanding and self-reported confidence related to impact analysis and explicit dynamics. In addition, open-ended student reflections provided qualitative insights into the learning process and served as formative feedback for refining and improving the instructional module in future offerings.

The following section summarizes the pre- and post-activity surveys and compares the two. It also summarizes qualitative feedback from pre- and post-activity surveys. Data were collected from 74 pre-activity and 68 post-activity respondents. It is noted that the participation of surveys were voluntary and anonymous, the response rates for the pre and post surveys were 87% and 80% respectively.

To quantify the survey data, Likert scale responses were coded numerically as:
1 = Not at all, 2 = Not very much, 3 = Somewhat, 4 = Very much, 5 = Extremely. Mean of the weighted Likert scale responses is calculated in column 1.

### 3.1 Quantitative Assessment of Student Confidence

Students' self-reported comfort with calculating beam deflection due to impact increased notably following the instructional module. The mean Likert score increased from 2.58 in the pre-activity survey to 3.44 in the post-activity survey, representing a change of 0.86 on a 5-point scale (Table 1). A Chi-square test of independence yielded a value of 29.6 ($p < 0.001$), indicating a statistically significant shift in comfort and perceived proficiency following the activity.

Table 1. Comfort finding beam deflection due to impact

| **Comfort finding beam deflection** | **Extremely** | **Very** | **Somewhat** | **Not Very** | **Not at all** |
|---|---|---|---|---|---|
| Pre-activity survey Q4 (n = 74)<br>Mean **=** 191/74 = **2.58** | 1 | 12 | 28 | 21 | 12 |
| Post-activity survey Q1 (n = 68)<br>Mean = 234/68 = **3.44** | 4 | 27 | 32 | 5 | 0 |

Student comfort using ANSYS LS-DYNA showed the largest improvement among all measured outcomes. The pre-activity mean Likert score was 1.47, reflecting minimal prior familiarity or confidence. Post-activity responses, averaged across two related survey questions, yielded a mean score of 3.47, representing a two-point increase on the Likert scale (Table 2). A Chi-square test confirmed a statistically significant change in the response distribution ($\chi^2 = 88$, $p < 0.001$).

Further analysis revealed a substantial shift in confidence categories. Prior to the activity, 92% of students reported low confidence (*Not very* or *Not at all*), while only 1% reported high confidence (*Very* or *Extremely*) (Table 3). Following the activity, low-confidence responses decreased to 10%, and high-confidence responses increased to 49%. Consistent with these findings, a pre-activity binary question indicated that only 26 of 74 students were aware of ANSYS LS-DYNA before the module, highlighting the limited baseline exposure to explicit dynamics software.

Table 2. Comfort using Ansys LS-Dyna

| **Comfort using ANSYS LS-Dyna** | **Extremely** | **Very** | **Somewhat** | **Not Very** | **Not at all** |
|---|---|---|---|---|---|
| Pre-activity survey Q6<br>Mean **=** 109/74 = 1.47; (n = 74) | 0 | 1 | 5 | 22 | 46 |
| Post-activity survey Q2 (Likelihood)<br>Mean = 244/68 = **3.59;** (n = 68) | 10 | 31 | 18 | 7 | 2 |
| Post-activity survey Q3 (Comfort)<br>Mean = 227 /68 = **3.34;** (n = 68) | 4 | 21 | 39 | 2 | 2 |
| Average Post-activity Survey (Mean 3.47) | 7 | 26 | 28.5 | 4.5 | 2 |

Table 3. Shift in Confidence Categories with comfort using Ansys LS-Dyna.

| Category | Pre | Post |
|---|---|---|
| **Not very + Not at all** | 92% | 10% |
| **Somewhat** | 7% | 42% |
| **Very + Extremely** | 1% | 49% |

### 3.2 Perceptions of Hands-On Learning

Students' perceptions of the helpfulness of hands-on learning remained high following the activity, although the mean Likert score decreased modestly from 4.28 (pre-activity) to 3.79 (post-activity) (Table 4). This decrease likely reflects a recalibration of expectations after direct engagement with the activity rather than a reduction in perceived instructional value. Supporting this interpretation, responses to a post-activity binary question indicated that 97% of students agreed that hands-on experiments enhanced or facilitated their understanding (Table 5).

Table 4. Helpfulness of hands-on experience

| Helpfulness of hands-on experience | Extremely | Very | Somewhat | Not Very | Not at all |
|---|---|---|---|---|---|
| Pre activity survey Q7 (Mean = **4.28**, n= 74) | 31 | 36 | 5 | 1 | 1 |
| Post-activity survey Q5 (Mean = **3.79**) n = 68 | 7 | 44 | 13 | 4 | 0 |

Table 5. Student Perceptions of the Impact of Hands-On Experiments on Learning

| Response (Post-question 4) | Number of Students | Percentage |
|---|---|---|
| Yes | 66 | 97% |
| No | 2 | 3% |
| Total | 68 | 100% |

Across all three survey topics (theoretical calculation of beam deflection, comfort or likelihood of using LS-DYNA, and the value of a hands-on experiment in facilitating learning), a clear pattern emerges: measurable outcomes improved (Figure 11).

Confidence-based measures, comfort with beam deflection calculation and use of ANSYS LS-DYNA, showed statistically significant gains, with large reductions in low-confidence responses and strong shifts toward higher comfort levels. The most significant improvement in student comfort and understanding occurred in software proficiency regarding ANSYS LS-DYNA. Students' technical comfort with impact-related mechanics and simulation software was minimal prior to the activity. As reflected in strongly positive pre-activity ratings, students expressed high expectations for the usefulness of hands-on learning prior to the activity. Following the activity, these perceptions became moderate and realistic.

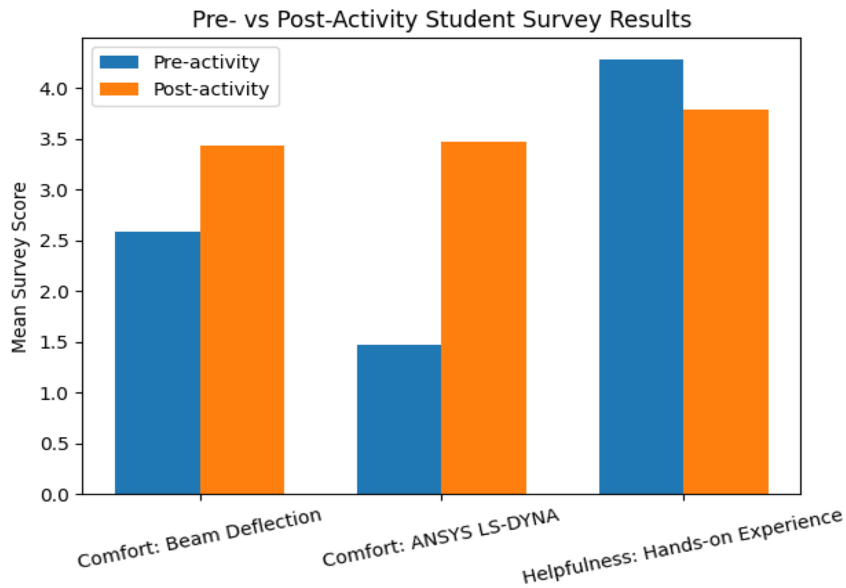


Figure 11. Pre- vs Post- activity student survey results

### 3.3. Qualitative Feedback and Conceptual Clarity

Qualitative responses provided deeper insight into the students' cognitive development throughout the module.

**Conceptual Foundations**: In pre-activity surveys, students correctly identified explicit dynamics as a method for high-speed, time-dependent problems (e.g., car crashes, ballistics). However, their understanding of "impact factors" was initially vague, often described as "guesses" or simple multipliers.

**Software Utility**: Post-activity feedback highlighted that the simulations were "fun to learn" and extremely helpful in understanding how FEA software tackles different engineering problems. Students noted that the "walkthrough" approach helped them connect physical properties to digital parameters.

**Identified Constraints**: Students demonstrated critical thinking regarding the limitations of simulation, noting that results are highly sensitive to user-defined boundary conditions (BCs), mesh density, and the exclusion of environmental variables like temperature or corrosion.

**Future Application**: A significant number of students expressed an intent to utilize ANSYS LS-DYNA for future senior design projects, indicating a transition from classroom exposure to professional tool adoption.

### 3.4 Summary of Assessment Outcomes

Across all metrics (theoretical calculation, software proficiency, and pedagogical value), the activity resulted in measurable improvement. The transition from high-level theoretical expectation to grounded, technical confidence suggests that the integration of LS-DYNA successfully bridged the gap between abstract impact mechanics and practical engineering application.

## 4. Conclusion

This paper presented the design, implementation, and assessment of an instructional module integrating explicit dynamics, impact experimentation, and LS-DYNA–based simulation within an undergraduate finite element analysis course. The module was motivated by the growing industrial relevance of impact analysis and the recognized gap in traditional FEA course.

Assessment results from pre- and post-activity surveys demonstrate that the module was effective in improving student confidence and self-reported proficiency in both conceptual and computational aspects of impact analysis. Statistically significant gains were observed in students' comfort with calculating beam deflection due to impact and in their comfort and likelihood of using ANSYS LS-DYNA. These findings indicate that the combination of guided tutorials, analytical reinforcement, and explicit dynamics simulation successfully lowered barriers to adopting advanced FEA tools. This work demonstrates that explicit dynamics and impact analysis can be successfully and meaningfully integrated into undergraduate FEA education, better preparing students for modern engineering practice.

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**Appendix**

Pre-activity Survey [11]

Question 1: What does explicit dynamics entail? Circle all the correct answers.

- Involves a time integration method for problems when speed is important
- Static analysis with low strain rates and non-linear problems.
- Used to solve problems for quickly changing conditions such as free falls and high-speed impacts.
- It deals with forces and motions that change slowly with time.

Question 2. Please provide three to five examples of real-world applications of impact analysis.

| |
|---|
| |

Question 3. What is an impact factor in impact analysis?

| |
|---|
| |

Question 4. How comfortable are you with finding deflection in a beam due to impact using theoretical mechanics (e.g., a weight dropping from a certain height)? Please cycle one answer.

| | | | | |
|---|---|---|---|---|
| Extremely | Very | Somewhat | Not very | Not at all |

Question 5. Are you aware of the ANSYS LS-Dyna? Please cycle one answer.

| | |
|---|---|
| Yes | No |

Question 6. How comfortable are you with using the ANSYS LS-Dyna to solve explicit dynamics problems? Please cycle one answer.

| | | | | |
|---|---|---|---|---|
| Extremely | Very | Somewhat | Not very | Not at all |

Question 7. Hands-on experiments enhance or facilitate your understanding of the topic. Please cycle one answer.

| | | | | |
|---|---|---|---|---|
| Extremely | Very | Somewhat | Not very | Not at all |

Question 8. What are the limitations of a simulation study?

| |
|---|
| |

**Post-activity Survey**

Question 1. How comfortable are you with finding deflection in a beam due to impact (e.g., a weight dropping from a certain height)? Please cycle one answer.

| | | | | |
|---|---|---|---|---|
| Extremely | Very | Somewhat | Not very | Not at all |

Question 2. How likely are you to use the finite element analysis software to perform impact analysis in current and/or future projects? Please cycle one answer.

| | | | | |
|---|---|---|---|---|
| Extremely | Very | Somewhat | Not very | Not at all |

Question 3. How comfortable are you with using the FEA software for impact analysis? Please cycle one answer.

| | | | | |
|---|---|---|---|---|
| Extremely | Very | Somewhat | Not very | Not at all |

Question 4. Do you think the hands-on experiments enhance or facilitate your understanding of the topic? Please cycle one answer.

| | |
|---|---|
| Yes | No |

Question5.  Please rate the hands-on experimental work experience on facilitating your understanding of the topic.

| | | | | |
|---|---|---|---|---|
| Extremely helpful | Very helpful | Somewhat helpful | Not very helpful | Not at all helpful |

Please provide feedback in the space below.

| |
|---|
| |