Development and Success of an Explosive Engineering Instrumentation Lab as a Distance Course

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Abstract

A graduate level course in scientific instrumentation for explosives has been re-imagined to support distance education. Serving a diverse student body that includes professionals in government, military, and industry roles, the course integrates remote learning with practical, hands-on experiences. To maintain the program's high standards, lab demonstrations are recorded and made accessible online. Additionally, several experiments can be performed using equipment available at home, such as cameras. The final project involves an on-campus weekend, during which students design and execute an experiment using three or more of the instrumentation techniques covered in the course. This collaborative project culminates in a research paper summarizing their findings. The course redevelopment has resulted in increased enrollment, positive student evaluations, and several peer-reviewed publications. This model demonstrates a successful hybrid approach that ensures distance learners gain equivalent hands-on experience and research opportunities as their on-campus counterparts.

Introduction

Explosives engineering is a specialized field that requires not only a solid foundation in theoretical knowledge but also the ability to design, execute, and analyze experiments [1], [2]. Success hinges on understanding how to identify key parameters, design diagnostics to capture critical data, and analyze the results. This often requires advanced diagnostics and measurement equipment to capture critical data during explosive events [3]. These diagnostics play an essential role in characterizing parameters such as pressure [4], shock velocity [5], and fragmentation patterns [6]. Given the nature of explosive events, the instrumentation used must be capable of fast response rates [7], [8], [9], [10], high sensitivity [3], and reliability under extreme conditions [3]. This makes diagnostics not only a cornerstone of research and development but also a vital aspect of safety, analysis, and engineering design.

In the field, opportunities to collect data are often limited to a single shot, making explosive tests high-stakes events, with limited room for error and significant costs associated with each test. Professionals in government, military, and industry roles must not only master the tools of the trade but also learn to interpret the data to drive decisions. This requires more than familiarity with instrumentation, it demands the ability to plan experiments, troubleshoot challenges, and critically analyze outcomes. Developing these skills in a structured and safe environment, free from the high stakes of real-world testing, is essential for preparing students for the demands of their career.

Distance education introduces additional challenges to learning design and diagnostic techniques. While remote learning has become more prevalent [11], [12], [13], [14], the challenge lies in ensuring that distance students achieve the same depth of understanding and skill development as their on-campus counterparts. This goes beyond simply teaching students to use equipment, it requires innovative teaching methods that balance hands-on activities with a focus on designing, interpreting, and analyzing experiments.

This paper explores the development and implementation of a hybrid learning model to address these challenges. Combining a flipped approach with blended learning, this model ensures that all students, whether on campus or remote, develop the ability to design experiments, collect high-quality data, and critically evaluate results. By front-loading theoretical content through asynchronous learning and reinforcing it with practical application during an in-person weekend at the end of the semester, the course provides a comprehensive learning experience. The structure levels the playing field between on-campus and distance learners, emphasizing shared learning outcomes prepares students to approach explosives engineering with the skills and confidence to succeed in any dynamic and demanding field.

Course Design and Learning Outcomes

The Explosives Instrumentation course was designed to equip students with the skills and knowledge necessary to analyze and interpret high-quality data collected during explosive events. Recognizing the importance of data integrity in this field, where there is often only one chance to collect usable data, the course emphasized not only the capabilities of instrumentation but also the processes of identifying, evaluating, and understanding the data these tools produce. This ensures that students grasp the theoretical foundations of explosive diagnostics while developing the practical analytical skills needed to understand the data.

The course is structured around weekly modules, each focusing on different aspects of explosive instrumentation and data analysis. Students begin with an introduction to photography where they learn fundamental imaging principles and methods for capturing experimental data. The following module covers high-speed camera applications, understanding size and velocity measurements, including discussion of measurement uncertainty and fiducial-based calibration. This leads into Schlieren and shadowgraph techniques, which are used for visualizing shock waves and other fluid flow phenomena in high-speed environments. The course then shifts to pressure measurements, beginning with an overview of pressure measurement and data acquisition systems (DAS). Students learn pressure prediction calculations, followed by data collection from open-air energetic events. Additional modules cover drone-based site surveys, focusing on aerial assessments of test locations, as well as boretrack and face profile measurements, which are essential for pre-blast assessments in rock blasting. The final technical module addresses seismograph-based vibration monitoring and measurement, allowing students to analyze ground effects and assess responses to explosive events. As they progress through individual modules, students also work in groups to design a final project, where they collect and analyze their own data using the instrumentation covered in the course.

Upon successful completion of the course, students will develop the ability to critically analyze and interpret experimental data, identifying trends, sources of error, and the reliability of results. Strong communication skills are also emphasized, with students expected to present technical findings in structured reports and synthesize information into professional-quality documents.

Course Learning Outcomes

The course aimed to achieve the following learning outcomes:

1. Effectively use and be aware of the capabilities of several pieces of instrumentation, including high speed cameras, data acquisition systems and seismographs.
2. Be able to effectively analyze data and present it in a succinct report.
3. As an assigned group, design an experiment using the instrumentation covered in class, gather the data and present the information both written and orally in the style of a peer reviewed conference paper and presentation.

Prerequisites and Student Background

This course is a 6000-level graduate course, primarily enrolling graduate students with backgrounds in engineering and applied sciences. Due to the technical nature of the subject, students are expected to have prior coursework or experience in fundamental physics, engineering mathematics, and data analysis. While there are no strict formal prerequisites other than graduate standing, familiarity with experimental methods and computational analysis is beneficial.

Challenges in Adapting to a Remote Format

Adapting this highly hands-on course to a remote learning format posed significant challenges. Explosive diagnostics traditionally require specialized equipment and facilities, which are difficult to replicate outside of a controlled laboratory setting. Prior to the transition, campus students attended weekly in-person labs. Shifting these labs to an online format required the creation of detailed video demonstrations and remote assignments to ensure all students could engage with the material effectively. Additionally, encouraging effective collaboration among students from diverse academic and professional backgrounds requires strategies to ensure equal participation and learning. Table 1 shows an example of the schedule for the semester with the class topic and assignment. The class was designed with a new module each week and assignment or report based on the topic and lab.

Table 1: Example class schedule

Date	**Class**	**Lab**	**Assignment**
Week 1	Photography	Photo lab Distance during lab weekend OR use personal DSLR	Short report (goals, results and analysis only) Student bio

Week 2	High Speed Phantom – Basics	Size and velocity measurements and uncertainty in measurement using high-speed cameras and fiducials	Results/Analysis
Week 3	Initial ideas		Initial Project Ideas
Week 4	Phantom - Schlieren/Shadowgraph	Shock wave visualization techniques	Full Report
Week 5	Pressure distribution/DAS overview	Pressure prediction calculations	short report (Camera reports due by end of week 5)
Week 6		Pressure data collection from open air energetic events	Full Report
Week 7	Group Design requirements		Group Design 1
Week 8	Drone	Site survey using drones	Analysis (Pressure reports due by end of week 8)
Week 9	Boretrack and face profile	Pre-blast measurements	Results/analysis
Week 10	Seismograph	Vibration monitoring and measurement	Full report Group Design 2
Week 11		Finish remaining reports	Blasting reports Due by end of week 11
Week 12	Fly in weekend	Fly in weekend	
Week 13			Group data collection and presentation
Week 14			Project draft 1 due
Week 15			
Week 16			Final project due

Assessment and Evaluation

The course assessments are designed to reflect the applied nature of the subject matter while ensuring that students develop strong analytical and problem-solving skills. Rather than relying on traditional exams, evaluation is structured around multiple components:

- **Weekly Lab Reports and Data Analysis (60%)** – Each week, students complete assignments that reinforce their understanding of experimental techniques and data analysis methods. These reports require students to analyze datasets, identify trends, and provide technical analysis, ensuring they develop a strong foundation in interpreting experimental results.
- **Capstone Design Project (40%)** – A major component of the course is the final project, where students apply the concepts learned throughout the semester to design and analyze an experiment. This project simulates real-world research challenges and often results in conference presentations or publications.
- **Participation and Collaboration** – Given the hybrid format, active engagement in discussions, peer feedback, and collaborative problem-solving exercises are integral to the learning process. While not formally assessed, not having active participation is often reflected in the student's design project grade.

While the course does not include traditional exams, the nature of the assignments and project work ensures that students demonstrate mastery of the material through applied learning.

Strategies for Remote Learning

1. Weekly video recordings of lab demonstrations provided students with a detailed visual representation of instrumentation setups and data collection methods. These recordings allowed students to review procedures at their own pace, ensuring they fully understood how the provided data was collected.
2. Students conducted basic experiments using widely available tools, such as cameras, to capture data remotely. This approach reinforced the importance of data quality and interpretation while enabling students to engage in hands-on activities without requiring access to specialized equipment.
3. Software associated with diagnostic tools was made available for installation on personal computers. This allowed students to process and analyze data remotely from its raw state, helping them build technical expertise in interpreting results from commonly used instrumentation, even when working outside a laboratory setting.

Equal Opportunities for On-Campus and Distance learning

A key strength of the hybrid course model, using both flipped classroom and blended classroom techniques, is the commitment to providing equal opportunities for both on-campus and remote learners, ensuring that all students engage meaningfully with the curriculum regardless of their location. The course is structured as a 1-credit hour lecture combined with a 2-hour lab component and places significant emphasis on data analysis and interpretation.

Rather than limiting the experience to hands-on use of instrumentation, both campus and remote students are required to analyze data and interpret results. This approach ensures that all students, regardless of physical access to equipment, can engage with the course learning objectives, designing experiments and interpreting results. This ensures that the curriculum meets the advanced expectations of a 6000-level course rather than a technician level training module, preparing students, both remote and on-campus, for the analytical and problem-solving challenges they will face in their professional roles.

Capstone Project Details

The capstone project served as the culmination of the course, integrating the skills students developed throughout the semester. It emphasized teamwork, critical thinking, and practical application, with the following process:

1. Groups were assigned by the instructor to ensure a mix of backgrounds and experiences. This diversity encouraged collaborative problem-solving and the sharing of varied perspectives.

2. Each group met to brainstorm and develop initial project ideas that required data from at least three pieces of equipment covered in the class. After discussion between the instructor and the group, a final project idea was selected. Projects were selected based on a priority of 1) safety 2) applicability of the equipment selection for the project design 3) likelihood to collect meaningful data, 4) expected time for data collection

3. Once the project was chosen, the group created a comprehensive test plan outlining the experiment design, data collection methods, and expected outcomes. The plan was refined with feedback from the instructor to ensure clarity and feasibility.

4. The capstone project included a dedicated on-campus weekend, during which students executed their experiments using university facilities. Each group had time to prepare for tests, perform the tests, and analyze the results. Additionally, the weekend had time allotted for students to make up labs that they might not have been able to do at home. Table 2 shows an example for the weekend schedule with times for each group to perform experimental testing.

   Each group synthesized their findings into a formal research paper, detailing their methodology, results, and conclusions. This conference style paper, along with an accompanying oral presentation, provided students with an opportunity to demonstrate their ability to analyze and communicate data effectively.

Table 2: Example weekend schedule

Friday		
8:00 am – 9:00 am		classroom welcome/meet groups/donuts/coffee
9:00 am – 1:00 pm		Group 1 Experimental Testing
1:00 pm - 2:00 pm		Make up Photo Lab
1:00 pm - 2:00 pm		Lunch
2:00 pm – 6:00 pm		Group 2 Experimental Testing

Saturday		
8 am – 12:00 pm		Group 3 Experimental Testing
12:00 pm - 1:00 pm		Make up Photo Lab
12:00 pm - 1:00 pm		Lunch
1:00 pm – 5:00 pm		Group 4 Experimental Testing
7:00:00 PM - ?		Social and Dinner

Sunday		
9:00 am – 12:00 pm		Presentations
12:00:00		adjourn – return to airport

By employing these strategies, the course successfully balanced the challenges of remote learning with the desire for hands-on experiences. The emphasis on data analysis, combined with structured teamwork and opportunities for diverse perspectives, ensured that students were well-prepared for the demands of the explosives engineering field.

Outcomes and Impacts

The transition of the explosives instrumentation course to a hybrid model that combined flipped and blended classroom techniques resulted in several notable outcomes. These included increased enrollment, valuable student feedback, peer-reviewed publications and conference presentations.

The multidisciplinary enrollment in the course, which includes students from nuclear, chemical, mechanical, systems, and electrical engineering backgrounds, shows its broad appeal and adaptability. This diversity enriches the collaborative experience and demonstrates the potential for expansion into other fields that require a combination of theoretical knowledge and hands-on expertise.

Enrollment Trends

The shift to a distance-accessible course broadened the reach of the program, attracting students from diverse professional backgrounds, including military, industry, and academia. This flexibility enabled students who might not have otherwise been able to attend a full time on-campus course to participate, thereby increasing the course's appeal and enrollment numbers. When the course was offered as an on campus only section, a total of four students were enrolled and participated in the class. The subsequent year, when offered as a hybrid class with flipped classroom and blended weekend, twenty students enrolled, a large number for a graduate level course offering in the department.

Student Feedback and Evaluations

Students praised the hybrid model for its effectiveness in balancing theoretical learning with hands-on experience. Below are key takeaways from student feedback:

- **Collaborative Experience**:
    - *"The combined distance/on-campus final lab weekend was one of the most fruitful experiences of my academic career."*
      Students highlighted the collaboration between distance and on-campus participants as a unique strength of the course. At the start of the semester students provided a bio outlining their industry experience, academic background, and technical skills. These bios were used to form diverse groups that deliberately paired individuals with complementary expertise and perspectives. The resulting collaborative environment mirrored the dynamics of professional interdisciplinary projects, fostering teamwork, knowledge sharing, and innovative problem-solving.
- **Hands-On Learning**:
    - *"The hybrid model enabled me as a distance student to feel included... while also providing the ability to travel to campus to conduct my own test."*
      The fly-in weekend allowed students to build personal connections with faculty and peers, moving beyond the limitations of virtual interaction. Working side-by-side during experiments fostered teamwork and collaboration, while the in-person environment brought a sense of relevance and inclusion that remote learning alone could not provide.
- **Professional Preparation**:
    - *"The requirement to design and instrument our own experiment ensured that I was comfortable using the equipment and interpreting the data."*
      The course equipped students with skills directly transferable to their professional roles, including experiment design, instrumentation, and data interpretation.
- **Networking Opportunities**:
    - *"We inadvertently got to learn about all the different career options... and make connections and friends."*
      Students appreciated the networking opportunities, likening the on-campus

weekend to a mini-conference where they met peers from industry and academia, fostering relationships that extended beyond the course.

Peer-Reviewed Publications and Conference Papers

The course's emphasis on high-quality experiment design and data analysis led to several student projects resulting in publications and conference presentations. Currently three journal articles have been published as a result of the course, with two more in development. Additionally, four conference papers have been presented at the International Society of Explosives Engineers conference. Table 3 shows the papers and conferences that have been published based on results and experiments in the class.

Table 3: Published output as a result of projects in class

Title	Published or Presented	Topic
Paper 1	Shock Waves Journal	Evaluation of measured and predicted air blast parameters
Paper 2	Propellants Explosives and Pyrotechnics Journal	Blast wave shaping
Paper 3	Shock Waves Journal	Safe distance calculations and traumatic brain injury
Conference 1	ISEE Conference	Effect of charge shape on shock propagation
Conference 2	ISEE Conference	Experimental compared to theoretical hemispherical explosive charge comparison
Conference 3	ISEE Conference	Blast waves in breaching
Conference 4	ISEE Conference	Unintentional detonation of non-electric systems

Conclusion

The hybrid model has not only increased enrollment but also provided a platform for students to gain practical skills directly applicable to their careers. Feedback consistently highlights the impact on preparing students for real-world challenges, with many noting its alignment with professional collaborative practices. Additionally, the quality of student projects has resulted in peer-reviewed publications and conference presentations, showcasing how the course advances research and innovation.

This program exemplifies the value of hybrid learning models in specialized fields. The combination of flexible remote learning, along with flipped and blended classroom approaches, addresses the unique demands of disciplines like explosives engineering, where access to advanced instrumentation and collaboration are essential. Moreover, the course structure ensures that distance students are fully integrated, promoting inclusivity and equal learning opportunities. By focusing on the importance of collecting, identifying, and analyzing high quality data, rather than just focusing on the use of instrumentation, both on campus and distance students are able to have similar learning experiences. Additionally, the approach offers opportunities for cross-disciplinary collaboration, enabling students from varied backgrounds to address complex, real-world problems together. Its ongoing evolution and potential for broader application position it at the forefront of innovative engineering education.

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