From Research to Prototype: A Hands-On Multidisciplinary Framework for Senior Design Education

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Work-in-Progress: From Research to Prototype: A Hands-On Multidisciplinary Framework for Senior Design Education

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Abstract:

This Work-in-Progress (WIP) paper presents a multidisciplinary continuity model that links a summer undergraduate research experience with a two-semester, six-credit Senior Design sequence. The model uses a structured handoff from summer research to capstone, where multidisciplinary teams work under faculty and industry mentorship to develop and test prototypes and communicate results through proposals, design reviews, presentations, weekly status reports, and technical documentation.

The pilot began with a summer research project focused on an acoustic localization subsystem for autonomous drones, using an Arduino UNO R4-based microcontroller setup for data acquisition and MATLAB for signal processing and direction-of-arrival estimation. Summer deliverables included a baseline data-collection pipeline, reusable analysis scripts, representative datasets, and documentation intended to support a clear handoff to a new capstone team. During the following academic year, a Senior Design team composed of Electrical and Mechanical Engineering majors extended the subsystem toward a complete prototype through scheduled milestones and weekly progress reporting with guidance from faculty mentors from both disciplines.

The paper describes the continuity structure, mentoring approach, and early implementation observations, with planned assessment focused on Senior Design student learning outcomes and multidisciplinary integration rather than parallel discipline work. Planned evaluation will use rubric-scored capstone artifacts, milestone performance evidence, mentor observations, and student reflection instruments collected across both semesters. Because the model is organized as a handoff package of code, data, requirements, and checklists, it can be adopted in other capstone sequences and extended to other project domains by replacing the technical subsystem while keeping the same research-to-capstone pipeline.

Keywords: multidisciplinary capstone, senior design, undergraduate research, acoustic localization, autonomous systems.

1. Introduction

Senior design capstone courses are intended to be a culminating experience in which students apply engineering design principles to open ended problems, work effectively in teams, communicate professionally, and deliver a functioning prototype. However, multidisciplinary capstone work creates additional challenges, including coordination across disciplines and the need for assessment methods that can capture team level integration rather than parallel discipline contributions. [1]

This Work-in-Progress (WIP) paper presents a multidisciplinary continuity model that links a funded summer undergraduate research experience with a subsequent two-semester Senior Design sequence through a structured handoff of technical and educational artifacts. The core contribution is a repeatable process for transferring requirements, code, data, test plans, and documentation from one student team to the next, so that the capstone team begins with a defined starting point rather than rebuilding from scratch. This continuity structure is positioned to support multidisciplinary learning by forcing early agreement on interfaces, integration plans, and shared verification activities. Prior work has described approaches that link undergraduate research to capstone design and motivate structured continuity across teams and semesters. [1]-[3]

The pilot case study uses an acoustic localization subsystem for autonomous drones as the technical vehicle for the continuity model. Acoustic localization is a passive method for estimating the direction of a sound source using a microphone array and time difference of arrival estimation. In the summer research phase, students developed a baseline data collection pipeline and initial MATLAB based signal processing scripts, producing a documented handoff package intended for reuse by the Senior Design team. During the academic year, a new Senior Design team composed of Electrical and Mechanical Engineering students extended the summer work toward a complete prototype through scheduled milestones, design reviews, and weekly progress reporting.

As a WIP, this paper does not claim validated learning gains. Instead, it clarifies what success will look like beyond technical feasibility and specifies a planned assessment approach. Beyond a working prototype, success is defined as evidence of multidisciplinary integration, including shared requirements and interfaces, a jointly owned system architecture, an integrated test plan, coordinated documentation, and team reflections that demonstrate cross-discipline decision making. Planned assessment will use rubric-scored artifacts and milestone deliverables, supported by reflection instruments and process evidence, consistent with prior work on rubric-based evaluation of capstone deliverables. [4] Planned evaluation will also consider how team activities relate to rubric-based performance measures in capstone settings. [5]

2. Senior Design sequence context

Fairfield University offers ENGR 4961-4962 Senior Design as a two-semester, six-credit capstone sequence in which multidisciplinary teams complete advanced engineering projects under faculty instructor/project manager and technical mentor guidance. In ENGR 4962, the spring course meets for 2.5 hours per week; teams are expected to meet outside class, submit weekly status reports, and meet with their industry mentor at least once every two weeks. The sequence concludes with a final team oral presentation, final written report, and working prototype, and course grades are based on project quality, presentations, reports, posters, videos, participation in meetings and project activities, and class activities rather than examinations.
The relevant Senior Design student learning outcomes (SLOs) for this WIP study are: SLO 1, form project teams, plan project activities, assess resource requirements and skill needs, and execute project tasks; SLO 2, apply analytical thinking to problems that include societal, business, and technical considerations; SLO 3, design and produce achievable solutions to technically challenging problems; SLO 4, communicate problems, concepts, and solutions effectively to multidisciplinary groups; and SLO 5, work as an integrated team toward a shared goal.

Teams are formed at the start of the fall term based on student majors and the needs of each project. Students submit their top three project choices, and a cross-major placement meeting is held to assign students to projects in a way that matches required roles, such as computer science for application development, electrical engineering for controls and hardware integration, and mechanical engineering for system dynamics and mechanical design. The placement process seeks to accommodate student preferences as much as possible while ensuring each project has the needed disciplinary coverage. Teams typically include at least three students from different majors, and most teams consist of four students. Each team is supported by an academic advisor and an industry mentor, and some projects include more than one academic advisor when multiple disciplines are central to the scope. In the acoustic localization pilot, the initial student team included three Mechanical Engineering students and one Electrical Engineering student.

The course structure includes explicit instruction in proposal development, work breakdown structure and scheduling, design specifications, engineering standards, professionalism, ethics, and intellectual property considerations. The sequence serves as the culminating major design experience and is aligned with ABET-oriented expectations through documented requirements, design under constraints, professional communication, teamwork, and evidence-based evaluation of student work products. [6] In this WIP, planned assessment will use existing Senior Design evidence sources, including weekly status reports, proposal and design-review materials, mentor observations, poster and presentation artifacts, final written report, final video, and prototype demonstration. These artifacts will be mapped to the SLOs above, with particular attention to multidisciplinary communication, integrated teamwork, shared interface decisions, cross-discipline tradeoffs, and jointly owned verification plans. Pilot-specific details, including the weekly expectations used in the summer research phase and the weekly deliverables used across both Senior Design semesters for this continuity model, are specified in Section 3.

3. Continuity model from summer research to Senior Design

The continuity model formalizes a pipeline in which (1) a summer research team explores feasibility and produces an initial dataset and baseline code, (2) faculty mentors curate deliverables into a handoff package, and (3) a new Senior Design team adopts the project and advances it toward a tested prototype. The handoff package is designed to reduce the initial ramp-up time in the fall semester and to help students begin Senior Design with a clearer problem definition, initial requirements, and a realistic integration plan. This approach is consistent with prior work that links undergraduate research and Senior Design by treating research outputs as a structured starting point for capstone design. [2], [3]

In the pilot, the summer research deliverables included a microphone array concept, microcontroller data acquisition code, MATLAB scripts for signal visualization and analysis, and a preliminary approach for direction estimation based on correlation and phase information. The Senior Design team then assumes responsibility for requirements refinement, packaging and mechanical integration, calibration procedures, robust testing across environments, and documentation aligned with capstone rubrics. To emphasize the multidisciplinary goal, the model distinguishes disciplinary contributions from integrative work, where integrative work requires shared interfaces, joint test planning, coordinated documentation, and cross-discipline design decisions.

3.1 Summer research phase weekly expectations

The summer phase is structured to produce both technical progress and a complete handoff package. A typical eight week schedule is as follows: Week 1 problem definition, background reading, and safety and equipment onboarding with an initial draft of requirements and success criteria; Week 2 hardware bring up and sensor characterization with documented wiring and configuration; Week 3 data acquisition pipeline and logging with controlled dataset collection and shared metadata conventions; Week 4 baseline MATLAB signal processing and visualization with repeatability checks; Week 5 baseline direction estimation using correlation and phase based approaches with defined failure modes; Week 6 preliminary integration concept with identified mechanical and electrical interfaces and a capstone integration plan; Week 7 draft verification and validation plan with environments, test cases, and calibration needs; and Week 8 finalized handoff package with cleaned code, compiled documentation, and a poster or internal demonstration.

3.2 Faculty curation and handoff package

Faculty mentors curate summer outputs into a handoff package that the Senior Design team receives at the start of the fall term. The package includes a one-page project brief and problem statement, initial requirements and constraints, hardware bill of materials and wiring diagrams, data collection procedures and sample datasets with metadata, baseline firmware and MATLAB scripts with version control guidance, an interface and integration plan describing mechanical and electrical boundaries, a draft verification and validation plan, and a risk register listing known limitations and open technical questions.

3.3 Senior design phase milestones and weekly deliverables

Consistent with common capstone structures, the Senior Design phase uses staged reviews and recurring weekly accountability. [7] Fall semester expectations typically include weekly progress reports and mentor meetings, proposal and project plan submission, requirements refinement, system architecture and interface definition, early prototype demonstration, and an initial test plan and risk mitigation plan. Spring semester expectations include subsystem integration, calibration and robustness testing across environments, verification and validation against the test plan, and preparation of the final report, poster, presentation, and video. The Spring 2026 syllabus also identifies project pass-off, group presentations, a research symposium poster presentation, final presentation, and final video/final report submission as course-level milestones.

3.4 WIP success definition for this model

In this WIP, success is defined as evidence that multidisciplinary integration is occurring and that continuity reduces restart costs. Evidence includes complete handoff artifacts, traceable requirements and interfaces, an integrated test plan owned by the whole team, and documentation quality that supports replication by a future team. Planned assessment focuses on rubric-scored deliverables and targeted reflection prompts that distinguish integrative decisions from parallel discipline work.

4. Technical case study: acoustic localization subsystem

Acoustic localization estimates a sound source direction by measuring time differences of arrival between spatially separated microphones and converting those delays into a direction estimate. [8], [9] In the pilot, students collected multi-channel microphone signals, inspected time and frequency content in MATLAB, and estimated inter-microphone delays using correlation-based methods as a baseline approach. [8]

The prototype used a microcontroller based data acquisition setup with a small microphone array, and data were exported to MATLAB for repeatable processing. The handoff package emphasizes reusable artifacts rather than performance claims, including wiring and configuration notes, data format conventions, baseline scripts, and representative datasets for the capstone team.

This subsystem creates clear multidisciplinary roles and integration points. Electrical engineering tasks include sensor selection, data acquisition, and delay estimation implementation. Mechanical engineering tasks include microphone placement geometry, mounting constraints, and mechanical integration with the vehicle. Integrative work occurs when the team jointly defines interfaces, agrees on sampling and logging conventions, and produces a shared verification plan and documentation that can be reused by future teams.

As a WIP, performance is not presented as finalized. Planned technical extensions and expanding tests across environments to support verification and validation in the Senior Design sequence. [8], [10]

5. Mentoring structure and multidisciplinary roles

In this case study, the team is supported by one industry mentor and two academic advisors, one from ECE and one from Mechanical Engineering. The ECE advisor focuses on sensing, data acquisition, signal processing, and verification planning, while the Mechanical Engineering advisor focuses on packaging, mounting, mechanical integration, and system level constraints. Both advisors support milestone readiness, documentation quality, and alignment with capstone expectations. The industry mentor provides application context, feasibility feedback, and practical constraints, and participates in key reviews. Regular mentor touchpoints include weekly progress updates, scheduled design reviews, and a final demonstration rehearsal. [7]

Disciplinary responsibilities are defined early, but the model emphasizes integrative work rather than parallel task completion. Integrative work is defined as shared requirements and interfaces, a jointly owned integration plan, a single test plan used across subsystems, and coordinated documentation that enables replication by a future team.

To enforce integration, mentors require three checkpoints: an interface definition review that locks mechanical and electrical boundaries, a test plan review that maps verification steps to requirements, and a documentation check that confirms the handoff package is complete and reusable. Planned assessment uses rubric-scored deliverables and targeted reflection prompts to distinguish integrative decisions from parallel discipline work. [7]

6. Preliminary outcomes and observations

Early observations are qualitative and based on mentor observations and student artifacts. Artifacts indicate progress in instrumenting hardware, collecting repeatable datasets, and interpreting frequency domain representations. Students also practiced communicating technical findings through poster style visualizations and structured updates. At this stage, no quantitative learning gains are claimed.

Preliminary technical observations include the ability to capture multi-channel audio signals, compute Fast Fourier Transform (FFT) and phase information, and estimate relative time delay between microphone channels for simple controlled sound sources. These results support feasibility while also revealing limitations that motivate the next phase of work. Beyond feasibility, success for this WIP is defined as evidence of multidisciplinary integration, including shared interfaces, a jointly owned test plan, and coordinated documentation that supports replication. Planned assessment will use rubric-scored artifacts and targeted reflection prompts to distinguish integrative work from parallel discipline work.

7. Challenges and planned improvements

Several challenges were identified during the pilot, and the next iteration will implement targeted process and documentation changes to strengthen continuity and multidisciplinary integration. Challenges and planned improvements include: (1) handoff clarity, addressed by standardizing a handoff package that includes a project brief, interface definitions, a risk register, and a verification plan template; (2) risk of parallel discipline work, addressed by requiring an early interface review, a shared test plan review, and a single integrated architecture document owned by the whole team; (3) inconsistent weekly reporting, addressed by a common weekly report format tied to requirements, integration status, and next week objectives; (4) technical robustness limits, addressed by expanding controlled test cases, documenting calibration steps, and defining robustness upgrades as an explicit capstone task; and (5) assessment alignment, addressed by adding rubric dimensions and reflection prompts that target integrative decisions, cross discipline tradeoffs, and shared ownership of verification.

8. WIP status and next steps

This project is in the WIP stage. The summer research phase and the initial handoff package have been completed, and the Senior Design team is currently implementing integration, testing, and documentation activities across the two-semester sequence. Planned next steps include completing verification and validation against a shared test plan, finalizing the capstone deliverables, and collecting assessment evidence from rubric-scored artifacts and targeted reflection prompts focused on multidisciplinary integration.

9. Conclusion

This WIP paper presented a multidisciplinary continuity model that links summer undergraduate research to a two-semester Senior Design sequence through a structured handoff of code, data, requirements, and documentation. The acoustic localization subsystem served as the case study vehicle, while the primary contribution is the repeatable process that supports continuity, integration planning, and shared verification across disciplines. The model is transferable because the same handoff and milestone structure can be applied to other capstone projects by substituting the technical subsystem while keeping the same research-to-capstone pipeline. Planned evaluation will use rubric-scored artifacts, milestone deliverables, mentor observations, and targeted reflections to capture evidence of multidisciplinary integration beyond technical feasibility. This aligns the continuity model with ABET-oriented expectations for major design experiences through documented requirements, design under constraints, professional communication, teamwork, and verification of project work products.

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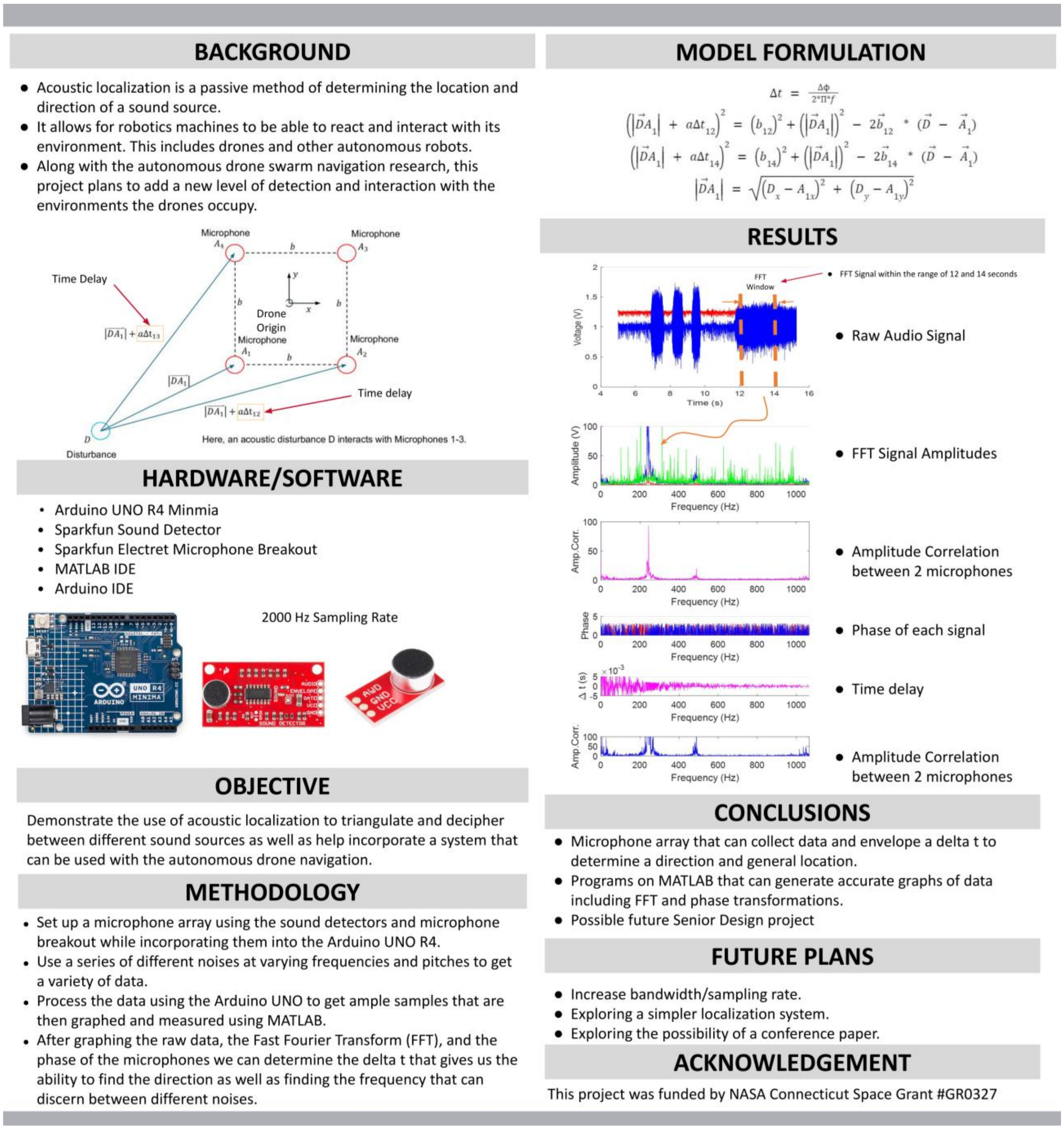
Appendix A: Summer 2024 Acoustic Localization Poster

Figure A1. Summer 2024 Undergraduate Research poster for the acoustic localization pilot project



Appendix B: Senior Design Project Acoustic Localization Poster

Figure B1. Senior Design acoustic localization project poster.