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Lessons Learned While Managing "Raise Your Hand," a Multidisciplinary Collaboration between Engineering and the Arts

Mary Ann Weitnauer
Dr. Jacqueline Rohde, Georgia Institute of Technology

Jacqueline (Jacki) Rohde is the Assessment Coordinator in the School of Electrical and Computer Engineering at the Georgia Institute of Technology. Her interests are in sociocultural norms in engineering and the professional development of engineering students.

Thomas Martin, Georgia Institute of Technology

Lessons learned while managing *Raise Your Hand*, a multidisciplinary collaboration between engineering and the arts

Abstract: *Raise Your Hand* is an immersive, interactive sensor-driven dynamic art exhibit. Vision tracking software changes the video projections, mechatronics, and music composition in response to the height of a visitor's raised arm. The 1 ½-year project brought together students and faculty from computer engineering, computer science, electrical engineering, industrial design, mechanical engineering, literature, media and communication, computational media, and music technology. Further, students were integrated into the project in different forms, including capstone design teams, Vertically Integrated Project (VIP) students, undergraduate research, extracurricular high school students, and a graduate student. Bringing this heterogeneity into harmony was a significant undertaking. We discuss some challenges we faced while managing the project and the ways in which we navigated those challenges. This work has value for the multidisciplinary engineering community by offering resources and recommendations for integrating engineering and the arts within an experiential project-based learning context. We describe challenges related to disciplinary language, real-time feedback, project timelines, and project documentation.

Introduction

Multidisciplinary project-based learning can have a valuable impact on undergraduate engineering students by providing opportunities for hands-on learning, real-world problem solving, and collaboration with other students from a variety of disciplinary backgrounds [1, 2]. Students can gain a sense of ownership over their contributions while also seeing the implications of their work in other disciplinary contexts [3]. These opportunities can be especially useful in preparing students for professional practice, where the work of engineers is fundamentally entangled with other constituents (e.g., technicians, marketing, leadership).

However, it can be challenging to effectively manage multidisciplinary projects in academic settings because these projects may differ from traditional lecture-based education in disciplinary silos. Students may not be used to working on long-time-scale projects or with other students outside their majors. Different academic programs may have different expectations about the skills that their students should master. Project leadership must establish common goals, structures, and schedules while also remaining agile enough to respond to arising needs. Multidisciplinary project-based-learning offers many benefits for engineering students, it also presents its own set of challenges that need to be overcome for students to fully benefit.

This work builds on previous scholarship from the Multidisciplinary Engineering Division that has addressed multidisciplinary project-based learning [4-6]. We discuss the management of a multidisciplinary project-based-learning program that created an immersive, interactive sensor-driven dynamic art exhibit called *Raise Your Hand*. The program brought together several undergraduate capstone design teams, multiple sub-teams connected through a Vertically Integrated Projects (VIP) team, undergraduate researchers, extracurricular high school students, and a graduate student. The contribution of this work is the description of the evolving project managements strategies that project leaders used to organize program efforts and integrate the student work for a successful deployment of the exhibit in Fall 2022.

In this paper, we discuss the **project context, team composition, learning outcomes, project stages,** and **key techniques** that coordinated and structured the project. The project context describes the design vision for the *Raise Your Hand* exhibit, which was inspired by forest imagery and broken into three physical sections with multiple sensor and interactive components. In the team composition section of this paper, we detail each sub-team, including its mode of participation (e.g., capstone design, undergraduate research) and student majors. We then discuss how project leadership navigated the different learning outcomes that were expected for each mode of participation. The project stages section addresses the logistics of carrying out the project from conception to deployment. Finally, the key techniques section addresses student assessment, ways of bringing students into the brainstorming process, project communication, and student documentation. We provide expansive detail to situate the decision-making appropriately. Our lessons learned are summarized in a table at the end of the document.

Synopsis of the Project and its Context

The *Raise Your Hand* exhibit was based at the Georgia Institute of Technology. Georgia Tech is a large, public university in the southern United States with a strong focus on science, technology, engineering, and math (STEM). To support this focus, the university's strategic plan expresses the value of "infus[ing] STEM disciplines with arts, humanities, and social sciences" [7]. The genesis of this project came from a meeting between the first author and leadership of the university's Ferst Center for the Arts at an online event for a local county digital arts program. The first author had been developing a team of students to create an interactive sensor-based art exhibit, although the exact requirements were still emerging at that time. The fortuitous connection with Georgia Tech's Ferst Center for the Arts led to an invitation in November 2021 to show the *Raise Your Hand* exhibit in the Center's lobby over a two-week period in the following year (November 1-14, 2022). A future public show date was a powerful attractor of students and motivator for the students and faculty. The institutional support for infusing the arts and engineering was an important background motivator in the context of an experimental project composed nearly entirely of undergraduates working only for academic credit.

The exhibit was a digital interactive forest in three side-by-side sections implemented as a tunnel, as shown in Figure 1. The interaction was marker-less, meaning that the participants did not wear anything special for the exhibit to work. The project had several objectives: (1) to delight and entertain participants as they discover the effects they could cause as they move their bodies, (2) a research objective to discover the effective interactive mechanisms when original music, video, and mechatronics, all interactive, are present together, (3) to inspire young people to go into STEM fields, and (4) to ultimately share all code, CAD, and methods online, so other groups could benefit from the team's experience. An informal documentary video of the exhibit is available at [8].

Sections 1 and 3 were dark and stylized, while Section 2 was bright and realistic. Each section had a camera and a Windows PC for pose detection of one person. Each camera feed was processed by a python program running on the PC using the Mediapipe Pose library [9], which produced the coordinates of key points (locations of major joints on the body). From the key points, the normalized highest hand height, a value between -1 and 1, was computed and sent via UDP packets over Ethernet to control the music and video and Arduino programs. In Section 2,

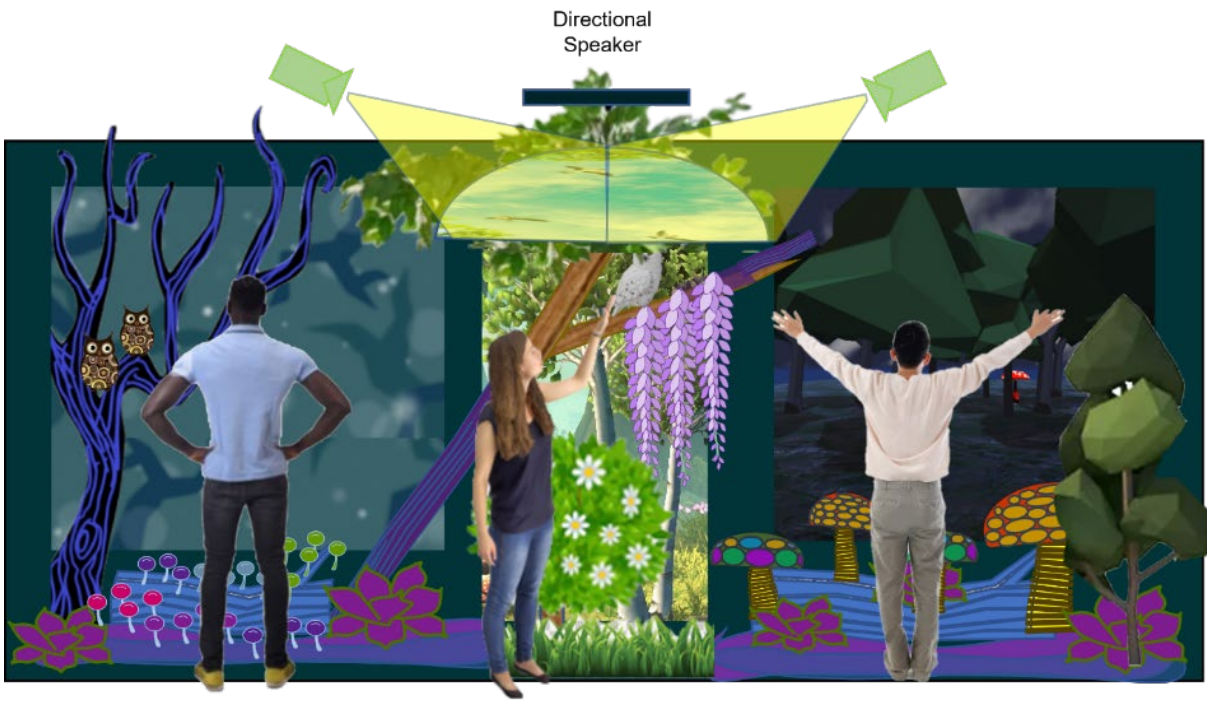


Figure 1. Early sketch of the *Raise Your Hand* exhibit, showing the three sections.

there was a second camera and python program running, to capture the facial expression of the participant using Mediapipe Face Mesh [10] and classify the facial expression using python code by jhan15 [11]. In Section 3, body tilt was also computed from the key points. The interactive music and video were generated by the Max 8 [12] and Unity [13] applications, respectively. The Unity videos were rear-projected onto three rear-projection wall screens, one per section. Section 2 also included an overhead dome screen that was illuminated by two projectors; the wall and dome projections were three virtual camera views of the same 3D world. The music played through two main speakers, a subwoofer, and a directional speaker over the dome screen. All physical moving objects were controlled by Arduino microcontrollers, paired with Ethernet Shields [14].

Each section had different mechatronic elements that were given unique names, which were important not only for consistent identification, but also to build sub-team identity. Section 1 mechatronics included the "Funky Tree Lights," with lights along the trunk that lit up as the hand was raised, the "Bright-eyed Owl", whose eyes got brighter with hand height, and the "Small Mushroom Lightshow", which included 10 groups of LED-lit small mushrooms, such that each group's lights blinked according to an independent Poisson process with an average rate that increased with hand height. Section 1 video added at random times short animated "sprite" flowers that flashed and then disappeared, also governed by a random process similar to the small mushrooms. As the Section 1 participant raised their hand, distinct musical tracks were added. The video in Section 2 had a flock of birds flying overhead and wind blowing the trees, such that the number of birds and the speed of the wind increased with hand height. MadMapper

(a) (b)

Figure 2. (a) a view of Section 3 of the exhibit, and (b) the exterior and "How It Works" display of Raise Your Hand exhibit

was used for projection mapping of the video onto the overhead dome screen. Section 2 mechatronics included a red lily that bloomed ("Blooming Flower") and a flower bush whose flowers would wave with increasing speed when hand was raised ("Waving Flower Bush"). There was also a "Snowy Owl" on the tree that would nod in approval if the facial expression was positive and shake head in disapproval if the facial expression was negative. The sounds from an increasing number of birds would be heard from the directional speaker. Section 3 video was of the "Unreal Forest", with trees in a grid, with large mushrooms scattered sparsely on the ground (a view of Section 3 is shown in Figure 2a). As the participant changed their body tilt, the location of the main camera in the Unity scene shifted, providing views down different corridors between trees. As the participant raised their hand, both the video mushrooms and the mechatronic "Large Mushrooms" in the foreground would light up and spin. Also in Section 3 was a "Lovely Interactive Worm" who emerged from the tree and whose head location would track the location of the participant's head. The timbre of the music would change from synth to Chinese Guzheng with height of hand. Together, the sections led to an immersive experience where multiple components reacted to the user's body and facial expression as they progressed through the exhibit.

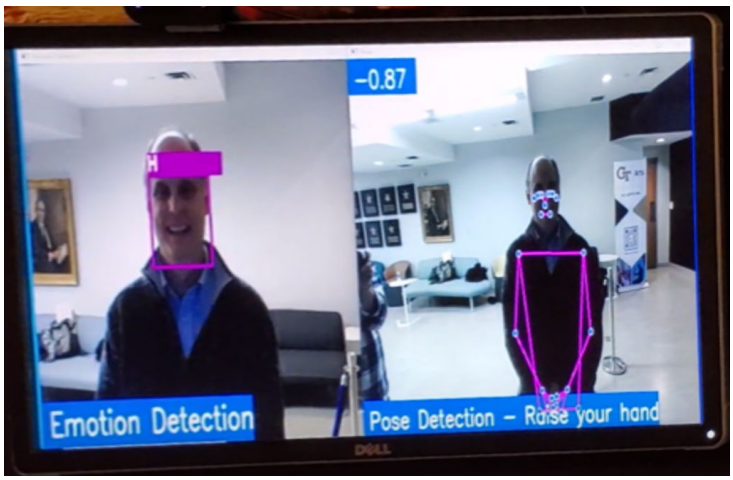


Figure 3. The emotion detection and pose key points superimposed on the participant in the "How It Works" display on the exterior of the exhibit. "H" is for "happy."

On the front exterior of the exhibit, shown in Figure 2b, was a "How It Works" display, which

included two computer monitors. One monitor showed a looping slide presentation explaining the exhibit and the other monitor had two windows with one showing the participant in the view of the camera with the Mediapipe Pose key points superimposed and the other window showing the face of the participant and its classification of the emotion, as shown in Figure 3.

Finally, there were two LIDARs: one scanned a vertical plane between participants and exhibit, triggering an "Intrusion Detected" sign on the video and shutting down of motors in the section of the intrusion; the second LIDAR scanned a horizontal plane to detect exhibit occupancy, to control certain aspects of the music and mechatronics.

Composition of the Project Team

The project was led by Mary Ann Weitnauer, Professor in the School of Electrical and Computer Engineering (ECE). The project team description that follows is primarily focused on the composition in Fall 2022, when the exhibit was displayed. The scoping to Fall 2022 is necessary because students moved onto and off the project in various capacity over the 1 ½-year project duration. Altogether, students of eight different majors participated in this project in Fall 2022. The Fall 2022 students were all undergraduates from Georgia Tech, except for a high-school student. Previous semesters also involved one graduate student, two summer research students from other universities, and another high school student. Table 1 lists the different sub-projects associated with *Raise Your Hand* and what type and size of team worked on it in Fall 2022. For each sub project, the objective was to design an attractive effect in the exhibit that would be triggered in specified ways, with no discernable delay, to certain poses and facial expressions of the participants.

The topmost sub teams in the table composed the Vertical Integrated Projects (VIP) team named Electronic ARTrium. VIP is a multidisciplinary project-based-learning, for-letter-grade-credit program available at approximately 44 colleges and universities in 13 countries [16]. VIP projects are long term, lasting four years at least. To start a team at Georgia Tech, a faculty member proposes the team to the VIP program, and the VIP program approves it. Then the VIP program promotes the team on their website and invites the professor to recruit students at poster sessions preceding each term. Having a VIP team affords a professor access to students of any major on campus and the students can stay with the VIP team for multiple semesters. VIP teams typically have 10 to 20 students. The Electronic ARTrium VIP team is co-instructed by Prof. Weitnauer and Dr. Thomas Martin, Chief Scientist of the Electro-optics Systems Laboratory at the Georgia Tech Research Institute. Enrollments in the Electronic ARTrium team since its inception to the time of this writing have been 22, 15, 21, and 24, for Fall 2021, Spring 2022, Fall 2022, and Spring 2023. Many if not all the computer science (CS) students on the VIP team were using VIP to satisfy their junior capstone design requirement, but this is transparent to the VIP instructors. Engineering students also have the option to use VIP to satisfy their capstone requirements, however none of the Electronic ARTrium students have done that so far.

The next three sub teams were single-semester capstone design teams. Two of these were multidisciplinary teams, meaning they involved students across different engineering schools; students on these teams register for the multidisciplinary course defined by their respective schools, to ensure these students receive discipline-specific instruction and meet the prerequisite and deliverable requirements of their respective schools for culminating design. The school of

the advisor of a multidisciplinary team is dictated by the majors of the majority of the students on the team. Prof. Weitnauer was the primary advisor for both multidisciplinary teams. The ME students in the two multidisciplinary capstone teams had secondary advisors from the School of ME. The other capstone team was completely within the School of Electrical and Computer Engineering (ECE).

Table 1. The different sub-projects associated with Raise Your Hand and what type and size of team worked on it in Fall 2022.

Sub-projects	**Sub-team name**	**Number of team members and discipline**
Max 8 interactive music	VIP: Sound Design	3 (all CS*)
Unity interactive video (3 scenes)	VIP: Visual Art Design	6 (3 CS, 1 CM*, 1 MT*, 1 LMC*)
Computer vision system, Ethernet networking, "How It Works" display	VIP: Sensor Processing and Networking	8 (6 CS, 1 CM, 1 Math)
Funky Tree Lights, Snowy Owl, Waving Flower Bush, Large Mushrooms	VIP: Electromechanical	4 (2 ME*, 1 ID*, 1 EE*)
Blooming Flower	Multidisciplinary Capstone design	6 (4 EE, 1 CmpE*, 1 ME)
Lovely Worm	Multidisciplinary Capstone design	5 (2 EE, 1 CmpE, 2 ME)
LIDAR Intrusion and Occupancy Detection	ECE Senior Capstone Design	6 (3 CmpE, 3 EE)
Interactive Music Composition	Undergraduate Research (School of Music)	1 (MT)
Small Mushroom Lightshow	Undergraduate Research (ECE)	1 (EE)
Bright-eyed Owl	High School student (ENGAGES program)	1 (N/A)

* CS = Computer Science, CM = Computational Media, MT = Music Technology, LMC = Literature, Media and Communications, ME = Mechanical Engineering, ID = Industrial Design, EE = Electrical Engineering, CmpE = Computer Engineering

Undergraduate research is one way to engage students over the summer (VIP is not offered in the summer) or who only want to work on the project for one or two semesters. At Georgia Tech, a professor within a certain school can co-advise a student from a major in a different school, if the other co-advisor is from the student's school. Prof. Weitnauer has had three undergraduate research students since the project began. She co-advised a Music Technology (MT) undergraduate researcher over the Spring, Summer and Fall 2022 semesters with Alex Cohen, Technical Director of the School of Music, and an Industrial Design (ID) undergraduate researcher in Summer 2022 with Dr. Noah Posner, Research Scientist and Lab Manager of Interactive Product Design Lab (IPDL), School of Industrial Design (this undergraduate student was also on the VIP team). The third undergraduate researcher was in ECE and worked Summer and Fall 2022. The project also had mentorship from five engineers from L3Harris (four ECE and one ME).

Learning Outcomes

The learning outcomes for each student in this project are based on the specific course the student is enrolled in, as indicated in Table 2. The courses involved (with their abbreviations in quotes) are:

- ME 4723 Interdisciplinary Capstone Design ("ME")
- ECE 4723 Interdisciplinary Capstone Design ("ECE")
- ECE 4873 ECE Single Semester Capstone Design ("ECE")
- VIP, by rank and # credit hours, e.g., VIP 4601 is senior ("4") and 1 credit hour ("1"); ("VIP")
- Undergraduate research, by major, rank, and semester, e.g., ECE 3951 is ECE, junior ("3"), first semester ("1")

ECE 4723 and ECE 4873 are both abbreviated by "ECE" in Table 2 because their learning outcomes are identical except "Work in teams…" in ECE 4823 is replaced by "Work in multidisciplinary teams…" in ECE 4723.

An "X" in the table and the letters in parentheses in the first column indicate the formal learning outcomes as published in the respective syllabi of the courses. For example, the first outcome in Table 2 is a formal learning outcome in the syllabus for ME4723 Interdisciplinary Capstone Design. In some cases, the authors have judged there is sufficient overlap between learning outcomes from multiple courses that they are listed together in one line in the table; for example, Outcome 6 is about working on a team, and the respective learning outcomes for the three capstone courses and the VIP course are all listed in that cell. Regarding formal learning outcomes, ME4723 has seven in rows 1-7. ECE 4723 and ECE 4823 have nine in rows 3,5,6,10-13, and VIP has three in rows 6,8,9. An outcome that is customary but not formal in the ECE capstones is indicated by an "C". An informal learning outcome implied by the nature of the project is indicated by "EA" in the table.

There are some differences between the learning outcomes of the ME and ECE capstone courses, which have the potential to create minor challenges for an exhibit-driven project such as Electronic ARTrium. Because real-world mechanical engineering often involves very physically large and expensive creations, such as centrifuges for pilot training, ME students at Georgia Tech are not required to build prototypes for their capstone projects and are generally discouraged from doing so, but rather a "proof-of-concept design" is considered sufficient, as indicated in Outcome 4. On the other hand, EE and CmpE capstone students are expected to build prototypes, since a wide range of real-world ECE creations are practical to build as prototypes in the context of capstone design; this requirement is reflected in Outcomes 11-13. In the multidisciplinary capstone program at Georgia Tech, professors (as well as sponsors) can propose capstone projects. The student teams bid on the proposed projects and the course instructor matches teams to projects based on their bids. Therefore, since Prof. Weitnauer clearly indicated in her proposals that the capstone projects would require built prototypes that would be used in the November exhibit, and she was the primary advisor, the Fall 2022 capstone students were eager to not only produce a prototype, but do so early, so it could be included in the exhibit. It is noted that for the next version of the exhibit, which will show in Spring or Fall 2024, Prof. Weitnauer is a secondary advisor for a Spring 2023 majority ME capstone team that is working on a robotic caterpillar, and the primary advisor has clarified that the only justification for building any prototype its necessity for testing. Therefore, at the time of this writing (early Spring 2023), the

authors are not sure if the Spring 2023 capstone team will produce a prototype. If they don't, the plan is that either an ECE-majority capstone team or the VIP team will finish the caterpillar so it can go into the next exhibit. The learning outcomes for undergraduate research are at the discretion of the advisors, so all its outcomes are indicated by "EA" in the table.

Table 2. Formal and informal learning outcomes for the four courses involved in the *Raise Your Hand* exhibit.

Learning Outcomes **Students will be able to…**		**VIP**	**Senior Capstone Design**		**Under-graduate Research**
			ME	**ECE**	
1	Identify relevant topics from earlier courses, then apply them to their design project (ME)		X*	C*	
2	Critically evaluate designs using engineering criteria and predictive usage (ME)		X		
3	Identify and specify design requirements, from general problem descriptions within the applicable realistic constraints (ME)/ Propose a project with demonstrable quantitative Technical Specifications (ECE) & Identify roles, resources, tradeoffs, and constraints (ECE)	EA*	X	X	EA
4	Systematically develop a design from the problem statement to a detailed, proof-of-concept design, meeting all of the specifications (ME)		X		
5	Clearly communicate design ideas and information (ME)/ Maintain and provide final documentation suitable for project reproduction or continuation (ECE)	EA	X	X	EA
6	Work collaboratively and responsibly as a team (ME)/ Work in (multidisciplinary for ECE 4723) teams with advisors and perhaps a sponsor (ECE)/ Experience different roles on a large, multidisciplinary team (VIP)	X	X	X	EA
7	Facilitate their learning by identifying design issues and questions that require additional investigation beyond their basic undergraduate curriculum knowledge, then formulating appropriate courses of action (ME)	EA	X	C	EA
8	Learn and practice professional skills (VIP)	X			
9	Make substantial contributions to the team project (VIP)	X			EA
10	Construct in a bounded time a project appropriate to their technical training (ECE)	EA	EA	X	EA
11	Demonstrate their results before a suitable audience (ECE)	EA	EA	X	EA
12	Execute a public presentation (ECE)	EA	EA	X	EA
13	Submit cyclical status reports (ECE)	EA		X	

* X = formal learning outcomes as published in the respective syllabi of the courses, C = learning outcomes that are customary but not formally published on the respective syllabi, EA = "Electronic Artrium", learning outcomes that are targeted through the Raise Your Hand exhibit, in addition to any formal or customary learning objectives.

Stages of the Project

The stages of the project are listed at a high-level in Figure 4 and in detail across semesters in Table 3. Some of the key techniques mentioned in this section are described in the following sections. The assignments in the VIP class for each semester, shown in Table 4, correlate to the stages and also mention the key techniques.

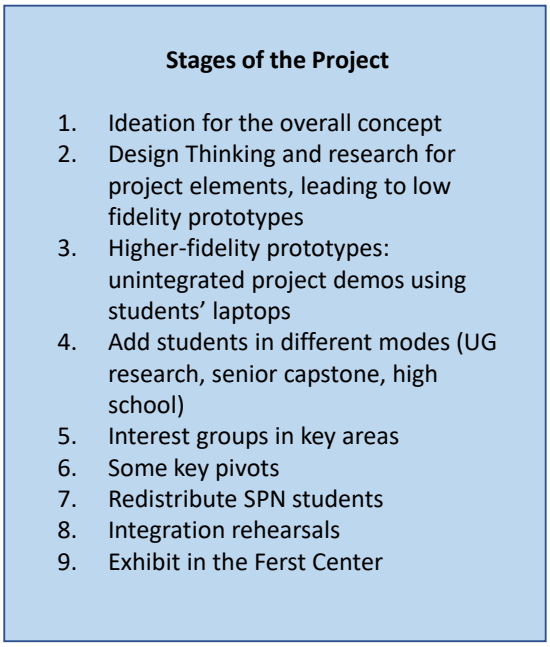


Figure 4. Stages of the *Raise Your Hand* project.

The first few weeks of the first semester were spent on ideation of the overall concept of the exhibit and definition of the distinct elements of the exhibit, which correspond to distinct projects. Next, students were asked to select projects to work on individually or in pairs. The students then spent the rest of the semester taking a Design Thinking approach (described below), which included researching methods and materials and developing low fidelity prototypes for each of their projects, such as the overhead dome screen and the computer vision system, which comprises cameras and pose detection software. Also, some students attempted to make a computer visual model of what the whole exhibit would look like.

In the second semester, the VIP team focused on developing higher fidelity prototypes for most of the projects and ended the semester with demonstrations of the projects. The instructors had expected these demonstrations to be cohesive demonstrations by each sub team, however, they ended up being done project-by-project, in series by individuals or pairs of students. Even though the exhibit plan called for desktop computers in the lab to be what controls the elements of the exhibit, because of convenience and difficulty in setting up the desktop computers, all of the projects were demonstrated using students' own laptops, which in the case of mechatronics obviated the need for discrete power supplies, and in the case of music and video, obviated the need to use software licensed for the lab so students were able to get individual student licenses as needed.

With pressure mounting to complete all exhibit elements and for the projects to be networked, Prof. Weitnauer recruited students from other modes, to supplement the labor of the VIP students. One School of Music undergraduate researcher joined the project in Spring 2022 and continued for the whole calendar year. Joining in the summer were two undergraduate researchers through the Georgia Tech Summer Undergraduate Research in Engineering/Sciences (SURE) program, a high school student through the Project ENGAGES programs, and two Georgia Tech undergraduate (GT UG) researchers. SURE sponsors under-represented minority (URM) and women students who come from other universities, while ENGAGES focuses on local URM high school students. The professor also put in three proposals to the single-semester ECE and Interdisciplinary capstone programs for Fall 2022 (the bidding process is done jointly between these programs) and all three proposals attracted capstone teams, with the professor as

the primary advisor. All these students from other modes (a total of 20) were added to the Electronic ARTrium team on Microsoft Teams ("Teams"), so they could see all the un-private content kept there and be able to reach anyone related to the *Raise Your Hand* project via Teams chat. Since the two SURE students were there only for the summer, one of the GT UG researchers elected to carry on the work of one SURE student and the professor carried on the work of the other SURE student.

Table 3. Key events and accomplishments in each semester of the *Raise Your Hand* project.

Fall 2021	Spring 2022	Summer 2022	Fall 2022
• Ideation for overall concept • Definition of the elements of the exhibit (i.e., the student projects) • Initial software tools selection • Build low fidelity prototypes • ETD* activities • Guest speaker: interactive art professional • Invited to do show in Ferst Center for the Arts building lobby	• Started a GT UG music research student • Revised software tools selection • ETD* activities • Began purchasing hardware • Visited the show site and Ferst Center staff • Began building higher-fidelity prototypes (still a lot of challenges) • Got UPD networking working, but it wasn't robust • Unintegrated project demos, on student's laptops • Reviewed goals for Fall 2022	• Hosted two visiting UG researchers to address pressing problems • Continued the UG music research student • One visiting UG researcher demonstrated a more robust networking solution • Designed the wood frame for the exhibit, decided PCs, and allocated one to each section • Got the Virtual LAN with private addresses	• Got a strong high school student and three capstone teams • Continued the UG music research student • Redistributed some SPN students; remaining ones allocated to support other sub-teams • Formed interest groups on power and networking • Some key pivots • ETD Activity • Several Set Construction Workshops • Two networking rehearsals • Moved to Ferst Center lobby • Ran the exhibit • Moved back to lab

To address two critical areas of need, power supplies and networking, and to span across the different modes of students, the instructors created a special interest channel in Teams for each and appointed a student leader for each group. Students joined these channels voluntarily and both were popular. Selected L3 Harris mentors were also members of these channels. The leaders organized meetings of their groups. Both groups had significant impact: the networking group's efforts led to a pivot and the power group managed, with key assistance from an L3Harris electrical engineer, to design and build the power supplies needed for all the elements that required them.

Shortly after the networking pivot and the subsequent finding and implementing of the final networking approach, the Sensor Processing and Networking sub team members needed other ways to contribute. They were redirected to creating the "How It Works" part of the exhibit,

which was displayed on the exterior and used to introduce visitors to the exhibit, while still supporting the other sub teams as needed with networking needs.

Finally, the exhibit, which was mostly constructed in the lab, was disassembled, transported to the Ferst Center lobby, and reassembled. Then after the show, it was again disassembled, transported back to the lab, and partially reassembled. All of this was accomplished cooperatively by all Electronic ARTrium members (VIP and non-VIP). During the two-week-long show, members of the VIP team took turns being guides for exhibit visitors during the peak hours.

Table 4. The semester schedules and key assignments for the VIP Team.

1	Stage	Fall 2021	Spring 2022	Fall 2022
2	General goals defined	Week 1	Week 1	Week 1
3	Ideation and vote	Week 2		
4	"Hello!" and response, Students select sub teams	Week 2	Week 2	Week 2
5	Master Punch List and Schedule			Week 2
6	How to work in teams and Design Thinking	Week 3		
7	Sub-team updates begin	Week 4	Week 3	Week 3
8	Set Building Workshops			Weeks 3 and 4
9	Self-grade Lab Notebook	Week 4	Week 4	Week 4
10	Effective Team Dynamics		Week 4	Week 5 (5FPC only)
11	Individual Semester Goals	Week 6	Week 6	Week 6
12	Midterm Peer Review	Week 7	Week 7	Week 7
13	Sub team updates each meeting	Weeks 4-15	Weeks 3-15	Weeks 3-15
14	Move Exhibit to Ferst Center lobby			Week 10
15	Effective Team Dynamics	Week 11		
16	Guiding and Monitoring the Exhibit			Weeks 11-12
17	Move exhibit back to lab			Week 13
18	Final Individual Video, Group Portfolio	Week 15	Week 15	Week 15

Key Techniques

This section describes several techniques used in the management of the *Raise Your Hand* project. Each technique is denoted by "KT" followed by a number.

KT 1: Mapping Grades to Project Activities

Although students were motivated by the altruistic goals of the project, it was obvious to the instructors that grades were a key motivator for most of the students. So, the distribution of points for the final grade for the VIP students must be included for a complete picture of project management. Table 5 shows the distribution of points for the VIP team in Fall 2022. The total is 101 rather than 100, because of a mistake in the syllabus. This distribution gave more weight to documentation, compared to the VIP-recommended distribution of approximately equal weight to documentation and records, personal accomplishments and contributions to team goals, and

teamwork and interaction. The instructor's Spring 2023 syllabus is more closely aligned with the VIP-recommended distribution. One can notice all the points allocated to activities that contribute to communications, teamwork, and the logistics of the show.

Table 5. Distribution of Fall 2022 grades for the VIP class.

Miscellaneous Early Activities: Hello! Video, Response to Hello! Video, Sub team Selection and Meeting Time, Team-building Exercise	1
Individual Semester Goals	2
Sub team contact info and Individual Task Descriptions	3
On-time attendance to Main Team Meetings	3
Weekly Sub Team Updates (sub team grade)	3
Scribe Duty	1
Personal Accomplishments	8
Contribution to Team Goals	8
Doing the Midterm Peer Evaluation	4
Doing the Final Peer Evaluation	4
Set Building and Moving	3
Helping with Show (guiding/monitoring/fixing)	3
Group Portfolio (final report & sub team grade)	25
Lab Notebook	28
Final Individual Video	5
Total	101

The Personal Accomplishments and Contribution to Team Goals are the more subjective grades. As was explained in the syllabus, the Personal Accomplishments grade depended heavily on evidence in the lab notebook that they pursued knowledge necessary for the project. The Contribution to Team Goals was based on the content in the lab notebook, the Group Portfolio, the Peer Reviews of the student, and the role played in the final project in the exhibit. The Final Individual Video was also used for deciding these subjective grades. The Final Individual Video was a 5*X minutes-long video recorded by each student, where X is the number of credits enrolled (1, 2 or 3). Either the video itself or a link to it was uploaded to Canvas. This video was a very helpful supplement for the instructor to gain a more complete understanding of the student's role in the project.

Students were informed at the beginning of the semester that their records, such as the Group Portfolios, lab notebooks, and Final Individual Videos for the VIP team and formal reports by the capstone teams, may be viewed by future students on the project and should contain enough information to enable such future students to duplicate the project. All the past Group Portfolios, capstone formal reports, and presentations, as well as selected lab notebooks have been made available to project members in Teams General Files > Library.

KT 2: Exposing students to design thinking and project management

The VIP students were exposed to several different design and project management methodologies over the course of the *Raise Your Hand* exhibit: a rapid brainstorming technique, Design Thinking, the three constraints of project management, a standard industrial project management process, the Agile concept of sprints, and a template for sub-team weekly presentations based on industrial project management standards, all explained below.

Rapid Brainstorming

In the first semester, to determine the overall project concept, the instructors used a very effective quick and mostly quiet voting technique in Week 2 [16]. The technique, which the instructors have used again recently for the next edition of the exhibit, was successful both times

in that the students made this crucial decision in one class period and were happy with and felt ownership of the concept of the exhibit they would create. The Fall 2021 version was slightly different from the Spring 2023 version; specifically, each student in Spring 2023 prepared only one "idea", a story board for a narrative, which was more detailed and time-consuming than in Fall 2021.

Figure 5. Example of the color-coding sticky labels used in the voting method.

The technique used in Fall 2021 began the week before voting day with an assignment for each student to dream up 10 ideas, each with a title, one or two sentences of description, and their name on a sticky note. Next, the students were to choose their two favorites of their 10 ideas and create two "mini posters", one for each of their favorite ideas, each with a drawing, a short description, and their name on the back. The students were encouraged to be free and creative with their ideas, staying only within the loose constraints given by the instructors (in Fall 2021, the constraints were interactive art exhibit with video, sound and mechatronics, such that the participants wear no sensors or markers). The students were also instructed that poster finalists would be selected, and the author of a finalist poster would give a one-minute oral description of their idea and answer any questions.

On voting day, upon entry to the classroom, each student was given two sets of color-coding sticky labels, one set was six dots of one color and the other set was three dots of another color. The sets were cut from a product such as shown in Figure 5. The students were told to put both their mini posters on one side of a long conference table and then move to the opposite side of the table to examine and vote only on the posters there, and not to talk at all. Students were guided to the appropriate side to achieve roughly equal numbers of posters on each side of the table. The students were given 15 minutes to vote with their six-dot set; they were free to distribute their dots in any way (they could put multiple dots on one poster if they liked). The instructors then gathered the three posters with the most dots from each side of the table and taped these "finalists" to the wall. Next, each author of the six finalist posters described their idea briefly and orally and answered any questions. Next, the students used their three-dot set of dots to vote on the six finalists. The instructors then combined the top vote-getting concepts to define the concept for the exhibit. The whole exercise took about 40 minutes.

Design Thinking

By giving a lecture early in the first semester, the instructors encouraged students to use "Design Thinking" to guide their efforts in defining the elements in the exhibit (which correspond to student projects). The Design Thinking steps are: empathizing with the customer (i.e., the participant, in the case of the exhibit), defining the elements in the exhibit, ideating about how to realize the elements, and next to make and test low fidelity prototypes (that is, prototypes made with a relatively small investment in time and energy and just good enough to be able to tell if the current approach is good). Design Thinking was developed in the late 1950's through a collaboration of faculty from the departments of Mechanical Engineering and Art and Architecture at Stanford University. Later developers at Stanford applied it to innovation

management in business through the company IDEO [17, 18]. The method values moving swiftly to prototype and test, then after failure, revising the prototype until it is adequate, rather than investing a great amount of time to create detailed specifications before building a prototype.

Three Constraints of Project Management

For project management, students were exposed to the three constraints of scope, time, and cost. Specifically, scope being the technical complexity of the exhibit, time being the deadline of the installation, and cost not being labor but rather the procurement of hardware and commercial software packages [19].

Product Development Process

In the prior section Stages of Project, the specific steps followed by the students were identified. These explicit steps were tailored from the standard product design process, starting with ideation and continuing through definition, prototype, design, testing, and finally commercialization – which was defined to be the installation of the exhibit for the general public to experience [20].

Agile Sprints

The Agile software process was partially introduced based on the concept of multiple sprints. A sprint includes the steps of design, develop, test, deploy, and review. Agile encourages the continuous iteration of development and testing in the entire software development lifecycle of the project [21].

KT3: Weekly presentation slide template

Weekly meetings were important to achieve a cohesive overall design, but also highlighted disciplinary differences. A structured agenda was established across all teams to maintain consistent expectations from each team's presentation. The topics, included the following:

- Subsystem block diagram
- Schedule review
- Accomplishments
- Setbacks
- Recoveries
- Next milestone discussion
- Additional discussions if required

Only a single slide was devoted to each topic. The subsystem block diagram, such as the example in Figure 6, was extremely helpful to helping instructors and students in a different sub team understand what the presenting sub team was doing. The instructors asked the students to always show "Input" on the left, "Processing" in the middle, and "Output on the right.

The instructors explained that the "Accomplishments" slide is not a bragging opportunity, but intended to simply communicate what the sub team has done, for the other sub teams' benefit; "Setbacks" are expected, and "Recoveries" are what you are doing to remedy the setbacks.

In summary, the students designed and installed the exhibit over a period of three semesters using a set of processes that not only provided structure and organization, but also exposed them to skills that are directly transferable to successful careers in industry.

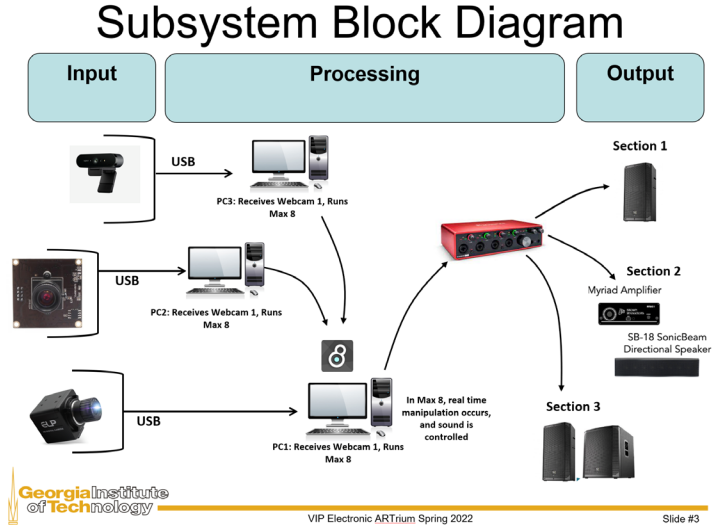


Figure 6. An example of the Subsystem Block Diagram slide.

KT 4: Effective electronic communications and record keeping

Prior to the beginning of the project, the VIP instructors queried several members of the School of ECE Advisory Board (mostly members of industry and distinguished alumni of the department) about their recommendation for inter-team communication; a majority recommended Teams, so the authors adopted it for the project, to expose students to a skill that would be attractive to employers after the students' graduation. All students and faculty involved in the project were members of the ARTrium VIP Microsoft Team and the L3Harris mentors were guest members (students signed a FERPA waiver to enable this). All were asked to enable the Teams notifications at the beginning of each semester.

The channels used in Spring 2023 are shown in Figure 7. The Fall 2022 channels were the same, except for Spring 2023 Capstone. In Fall 2022, everyone had access to the General, Sub-team Updates, and System Integration channels. Each sub-team, each capstone team, the two special-interest groups (Power Supply and ROS2 Interest), and the instructors ("Working area") had private channels. The instructors had access to all channels. The reason for having most of the channels private was so the whole team would not be annoyed by too many notifications.

In Fall 2022, as an icebreaker and an introduction to Teams, and because we were still masking because of COVID-19, "Hello! Video" and "Response to Hello! Video" assignments were made in the VIP class on the first day of class, due in five and seven days, respectively. For the Hello! Video, each student made a ~1 min video without mask on, saying name, major, rank, where from, hobbies, and what they did over the summer. The author started the thread in General Post and the students were to post links to their videos and their responses in that thread. The "Response" assignment was to post positive and thoughtful comments to at least two team members. In Spring 2023, because most people were no longer wearing masks, the "Hello!

Video" was replaced by a "Hello! Message" assignment. Reading these posts gave the instructors a sensitivity to what types of roles each student might enjoy.

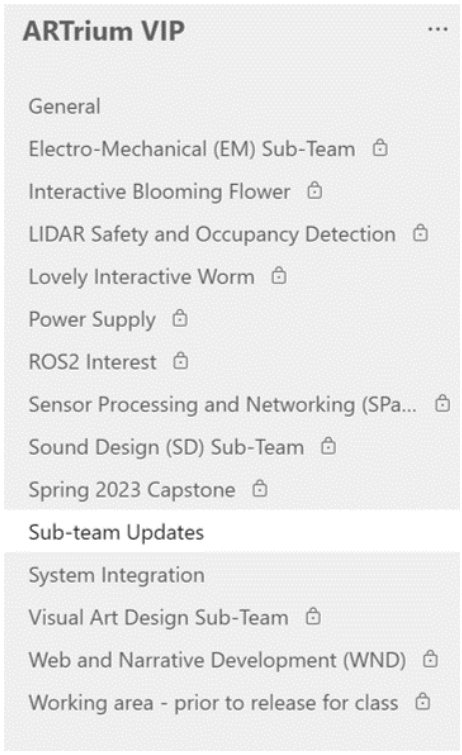


Figure 7. Channels on MS Teams in Spring 2023.

For everyday communications, the instructors found that most sub teams used Post in the sub team Team's channel, but others elected to use the GroupMe chat phone app. For any communications explicitly about a graded item, the instructors used Canvas Announcements, to avoid grievances. For other communications, because Canvas announcements didn't reach the whole project team, the instructors either posted in the General or sub team channels or used Teams chat to individuals or other groups of students. Despite the GroupMe use, the students still seemed responsive to posts involving the instructors, but the instructors regretted not being able to see the GroupMe communications.

Beyond the techniques using Teams, the instructors also made changes to how students kept project records. In Fall 2021, the VIP instructors noticed that many students were using their devices for other things besides taking notes in the Main Meeting and the students' engagement during class time appeared to be low. Also, having all sub teams giving oral presentations each Main Meeting was causing the meeting to go overtime. So, in Spring 2022, personal devices (tablets, laptops, phones) were no longer allowed to be open in the Main Meeting. Students had to take their own notes on paper in the Main Meeting and afterwards they had to transcribe their notes to electronic form so the notes could be placed in the lab notebook. Consequently, there was high variability in the quality of the meeting notes in the lab notebooks. In informal feedback and in the formal online course evaluations for Spring 2022, students complained about how time-consuming this process was. Also, the instructor noticed that some students were copying the electronic meeting notes of other students.

Therefore, with the aim of everyone having access to high-quality meeting notes while keeping the ban on devices, the instructors adopted in Fall 2022 a scribe system for Main Meeting notes. Specifically, two students are designated as scribes for each meeting, and Scribe Duty is allotted one point of the overall grade. Only the scribes are allowed to use their devices to take notes. Before midnight after the meeting, the scribes are supposed to merge their notes and post them in the Teams folder General Files > Main Meeting Notes in folders named by the date in year-month-day format, which ensures chronological ordering of folders and ease of lookup. This folder also contained materials from the instructors and any slides presented. The scribes place their names at the top of the document. Other students are encouraged to simply copy and paste these notes into their lab notebooks and edit them if they like. The scribes seem proud of their notes and have been posting them in a timely fashion. Also, to keep the class from going

overtime, only two sub teams gave oral presentations in the weekly class meeting and the other sub teams uploaded brief written updates in the Post of the Sub-team Updates Teams channel.

The new scribe and sub team reporting system was successful in Fall 2022, in terms of raising the quality of the Main Meeting notes and leaving some class time for students to talk with each other and has continued for Spring 2023.

KT5: Building teamwork skills through Effective Team Dynamics (ETD) activities

Good teamwork skills were critical for the success of the *Raise Your Hand* project. Also, the ability to work effectively in teams is a formal outcome of the VIP and capstone design programs, as shown in Table 3, Line 6. To help the VIP students achieve this, the instructors used a few of the activities in the Effective Team Dynamics (ETD) curriculum [22]. ETD builds on prior work on teaming, including the Clifton Strengths® [22-25]. Specifically, ETD "helps students identify their patterns of thought and behavior in a team, name and build on their strengths, identify the diverse strengths of any team, and interpret behaviors of their team members in productive ways" [22, p. 2].

The weeks that ETD were used are indicated by Lines 10 and 15 in the semester schedules in Table 4. The instructors discovered ETD in mid-Fall 2021, so it was used a bit late that semester. In both Fall 2021 and Spring 2022, one class period each semester was allocated to hear a lecture from an ETD faculty member and do selected activities. The instructors did not take a whole class period for ETD in Fall 2022, because class time was needed to get ready for the show. However, the out-of-class Five-Finger Pulse Check (FFPC) activity was done every semester, just after the in-class activities in those semesters, even though FFPC took up a whole sub team meeting and an hour of instructor's time, because the instructors found it to be so useful.

The EDT in-class activities included the "Choosing a Card" and "I Bring" activities, which were done by sub teams in different corners of the classroom. In the "Choosing a Card" activity, cards with different cartoons on them, for example one shows several characters with the center one obviously angry, are laid on the table and each sub team member chooses a card that represents their sub team and is later asked to tell their sub team members why they chose that card. In the "I Bring" activity, each sub team member is asked to write on the same sheet of paper, their name, what they bring (from a provided list), fills in the blank, "This enables the team to…"; they also choose one statement from the list that is not their strength and writes the answer to "How would a team member who is good at this enhance your performance on a team?". Because these conversations are happening concurrently in one class period, it was challenging for the instructors to hear what each student was saying, however they were able to read the "I bring" sheets. The instructors were pleasantly surprised to see how the students used the "I Bring" information to organize the sub team members' responsibilities to better match each other's interests and abilities. Some students included the "I Bring" information about themselves and their team members in their lab notebooks.

For the Five Finger Pulse Check (FFPC), the instructors split up the four sub teams into two groups of two, and each instructor attended their assigned two sub team meetings in a specified week, to lead this exercise. To begin the activity, the instructor tells the students that the usefulness of this exercise depends on the honesty of the responses, and it has been very

effective in improving the function of the teams. Also, because these are honest responses that reflect the student's experience, there are no right or wrong answers and there will be no retribution for anything said. Then the instructor says they will ask a question and then count down "3, 2, 1". On "1", each student is supposed to hold up a number of fingers on one hand to indicate their answer, with five fingers meaning the most positive response and one finger meaning a very negative response. In Fall 2021, the question was, "How would you rate the team in terms of working together?". The students need to keep holding their fingers in that position until the instructor notes how many fingers were held up by each student. Next, the students who showed the fewest fingers are asked, one at a time, to explain why they chose that number of fingers. After each student explains their choice, the instructor asks the group what they think about that and notes the level of agreement. Once all the students with that number of fingers chosen finishes, then the students with the next highest number of fingers explain their choices, and so on. After the discussion of the last student's choice is finished, the team makes an Action Plan, to address the issues for which there was significant agreement. After the meeting, the Action Plans of each sub team were posted on Teams in the General channel, so other sub teams could benefit from seeing other's plans and to encourage accountability. In subsequent sub team updates, each sub team was expected to give an update on their progress with the Action Plan.

The instructors found that in every sub team and in every semester, very actionable information emerged from the FFPC. The FFPC seemed to give the students permission and motivation to tell what was bothering them. One outcome was that the instructors changed the class meeting format to give the students more time during the meeting period to communicate with each other, particularly with others from other sub teams, about the project. The instructors felt the FFPC was a great investment of their time and energy.

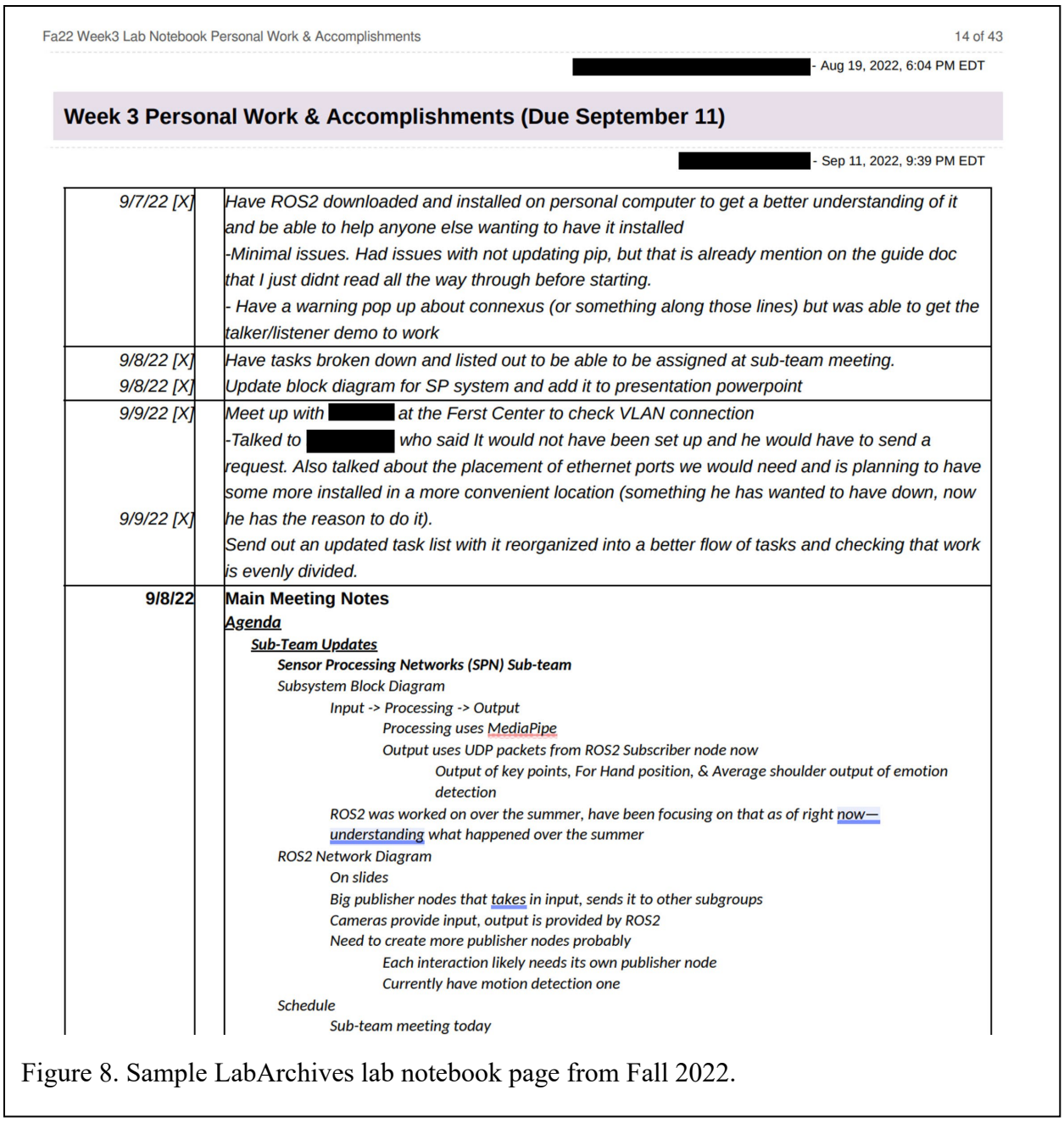
KT6: Electronic lab notebooks

The VIP and ECE capstone design programs require lab notebooks. The notebooks are intended to allow students to track and document their efforts, to allow instructors to assess individual student contributions, and to provide useful reference documents to future students. The Multi-disciplinary capstone program does not generally require them but allows the primary advisor to require them of all students on the team if the primary advisor's school requires them. Traditionally, these have been paper lab notebooks. However, in July 2021, the instructors were informed that Georgia Tech had acquired the lab notebook management platform LabArchives, integrated with Canvas, and the faculty were invited to join an early adopter cohort. So, for Fall 2021, the instructors decided to require electronic LabArchive notebooks for each student on the VIP team. In Fall 2022, when the first capstone teams became involved with the project, and Prof. Weitnauer was the primary advisor for all three of them, so the capstone teams were also required to use the LabArchive notebooks.

In Fall 2021 and Spring 2022, there were only two lab notebook assignments for the VIP team, a midterm one and a final one, to be consistent with the standard lab notebook assignments in VIP. Each assignment was a "page" in LabArchives; a LabArchives page can be arbitrarily long. This enabled the entire lab notebook (both the midterm and final lab notebooks) to be exported as a single PDF file. The page is locked for further editing when the student submits it in Canvas. The LabArchives notebook requirements were like the VIP paper notebook requirements, including

To Do List checkboxes for items to be done that are checked-off and dated when done, detailed meeting notes, and detailed technical notes.

The format of the LabArchives notebook is designed by the instructor. The format used in this project takes the form of a table with three columns. The left column is for dates for notes and meetings, To Do check boxes, and To Do completion dates, and is right justified. The middle column is intended to be empty and is there only to create horizontal space between text. The right column is for notes, links, photos, sketches, etc., and is left justified. An example from Fall 2022 of the desired format of the lab notebook is shown in Figure 8. One problem with this format is how To Do check boxes in the left column may not align with the To Do item in the right column, illustrated by the second "9/9/22 [X]," which should align with "Send out an updated task list." This can be remedied by inserting a new line in the table.



Fa22 Week3 Lab Notebook Personal Work & Accomplishments 14 of 43

[redacted] - Aug 19, 2022, 6:04 PM EDT

Week 3 Personal Work & Accomplishments (Due September 11)

[redacted] - Sep 11, 2022, 9:39 PM EDT

9/7/22 [X]	*Have ROS2 downloaded and installed on personal computer to get a better understanding of it and be able to help anyone else wanting to have it installed* *-Minimal issues. Had issues with not updating pip, but that is already mention on the guide doc that I just didnt read all the way through before starting.* *- Have a warning pop up about connexus (or something along those lines) but was able to get the talker/listener demo to work*
9/8/22 [X] *9/8/22 [X]*	*Have tasks broken down and listed out to be able to be assigned at sub-team meeting.* *Update block diagram for SP system and add it to presentation powerpoint*
9/9/22 [X] *9/9/22 [X]*	*Meet up with [redacted] at the Ferst Center to check VLAN connection* *-Talked to [redacted] who said It would not have been set up and he would have to send a request. Also talked about the placement of ethernet ports we would need and is planning to have some more installed in a more convenient location (something he has wanted to have down, now he has the reason to do it).* *Send out an updated task list with it reorganized into a better flow of tasks and checking that work is evenly divided.*
9/8/22	**Main Meeting Notes** ***Agenda*** ***Sub-Team Updates*** ***Sensor Processing Networks (SPN) Sub-team*** *Subsystem Block Diagram* *Input -> Processing -> Output* *Processing uses MediaPipe* *Output uses UDP packets from ROS2 Subscriber node now* *Output of key points, For Hand position, & Average shoulder output of emotion detection* *ROS2 was worked on over the summer, have been focusing on that as of right now— understanding what happened over the summer* *ROS2 Network Diagram* *On slides* *Big publisher nodes that takes in input, sends it to other subgroups* *Cameras provide input, output is provided by ROS2* *Need to create more publisher nodes probably* *Each interaction likely needs its own publisher node* *Currently have motion detection one* *Schedule* *Sub-team meeting today*

Figure 8. Sample LabArchives lab notebook page from Fall 2022.

Because the instructor can view the LabArchive notebooks at any time, the VIP instructor noticed that most students kept up their lab notebooks well in the first few weeks of the semester (leading up to the midterm notebook due date), but in the latter half of the semester, many were not updating their final lab notebooks in a timely fashion. In their rush to write the final lab notebook before it was due, many students wrote very superficially about what they did, with scant details, and their "To Do" items were obviously written after the fact. In other words, the notebook assignment failed in its planning function and its value to future students was low. This was unfortunate, because in the latter half of the semester, most students were past the learning curves for the skills they were trying to acquire and they were in a contributing phase, when their notes would be most helpful to future students.

To attempt to remedy this problem, in Spring 2022, the instructor allotted one point of the final grade to an "Interim Lab Notebook Check" on a Tuesday sometime between 24 February and 14 April, to be selected without notice. The basis for the grade was documented with screen shots and the date of inspection not shared except by request at the end of the semester. This helped, but still the quality of many lab notebooks was unsatisfactory.

After consulting some of the more active students on the team towards the end of Spring 2022, the instructor decided to switch to weekly lab notebook assignments. Each of 14 weekly assignments was worth two points of the final grade. Each weekly lab notebook was a page in the LabArchives notebook. In Fall 2022, there were three capstone teams in addition to the VIP team, a total of 41 students (see last column in Table 1), and all were required to submit to Canvas weekly electronic lab notebooks using the external tool LabArchives through Canvas. While this was an increased burden to the instructor, to both create the assignments in Canvas and to grade them, it increased the quality of the lab notebooks. The instructor was able to provide feedback, via points taken off and Canvas comments, to encourage the students to improve the quality of their lab notebooks. The instructor also learned news about the project that was not otherwise communicated and was able to follow up with timely questions or corrective action. An example of timely news learned from weekly lab notebooks was that two people were doing the same thing (i.e., redundant work), when they shouldn't have been, so the instructor was able to bring this to their and their sub team leader's attention, so they could redirect and contribute more productively to the project. After the first few weeks of Fall 2022 semester, the instructor informally queried about five students who had been on the team in Spring 2022 about how they liked having weekly lab notebook assignments and to her surprise they liked them, because, they said, the assignments motivated them to stay on top of and write about their individual projects.

In Spring 2023, the burden of making the assignments was reduced somewhat because all assignments from Fall 2022 of both LabArchives and Canvas can be imported respectively into Spring 2023, however, it seems, the linking from Canvas to LabArchives as an external tool still must be done one assignment at a time in Canvas. Also, the worth of each weekly page was reduced to put the documentation part of the VIP grade more in line with the VIP program recommendations.

KT7: Bridging between disciplines and modes

By Fall 2022, the overall team was quite heterogeneous, with eight disciplines (see Table 1, last column), three ranks (sophomore, junior, senior), and four modes (high school, UG research, VIP, senior capstone). As seniors, the capstone teams had more technical expertise than the VIP team, which was mostly sophomores and juniors. The capstone students also had more time for their projects because they were all taking three credit hours, while the VIP students were taking mostly one or two credit hours.

The exhibit was highly integrated, implying much interdependence between projects. For example, the LIDAR capstone team's occupancy indicator was used by the MT UG researcher to switch compositions between "empty exhibit" music and interactive music, by the Blooming Flower capstone team to relax the Flexinol® (which draws a lot of current) and the Lovely

Worm capstone team to bring the worm into the hole in the tree, when the exhibit was empty. The LIDAR team's intrusion indicators were used by the VIP Visual Art Design sub team to put up a "Intrusion Detected, Back Off" banner and by the VIP Electromechanical sub team to shut off the motors to avoid visitor injury, in the section of the intrusion. The LIDAR team had to work closely with the VIP Sensor Processing and Networking sub team to design the format of the UDP packets to carry the intrusion and detection information and with all students whose projects had to read those packets.

The General Channel in Teams helped the project leader cope with the heterogeneity of the project team. The project leader used the Teams General Post for posts useful to all project members, such as "After-hours Access to the Van Leer Building" (the build location), "Update on Ferst Center Plans", "Private Address Space for the Electronic ARTrium installation network", "Calling All Hands: Please give times you can help move", and "I'm going to Home Depot and Hobby Lobby shortly – do you need anything?". The project leader also posted photos and videos of project-wide activities. Other project members also posted in General, for example, a capstone team member posted, "UDP Arduino Library" and the VIP sub teams posted their Five-Finger Pulse Check results there.

Including the students in planning meetings with the Ferst Center staff made the project become more "real" for the students and increased their motivation, regardless of their technical discipline. Other very effective activities that connected students were set building, moving, and guiding in the exhibit. It was key that that each student was informed orally and in writing at the beginning of the semester that they were expected to participate in these activities and that these activities were necessary to have a successful show for the public. For the VIP team, as shown in Table 5, these were graded items, but they were voluntary for all other project students.

The set building "Workshops" provided an opportunity for students of all modes to learn how to use power tools and was a fun social activity. The professor often provided pizza or doughnuts. The sign-up slots were designed to ensure that each workshop had four to six students. The students were usually assigned in pairs to various tasks. The Interdisciplinary Design Center, a makerspace with 3D printers, laser cutters, electronics stations, exhaust fume room, and well outfitted woodworking shop, was conveniently nearby to the lab and had Peer Instructors who would help any student learn how to use the tools. There were also other makerspaces around campus students could use, with some different kinds of equipment.

Moving and assembly or disassembly was another all-mode activity. For the capstone students, because their help with the exhibit was not part of their grade, the professor could only ask in General Post for "All Hands" help to move, with a link to a web app poll to get students' availabilities, and post the resulting schedule in General Files, showing when each person was scheduled to help. All students participated, except one capstone team who was particularly proud of their project was not responding to the call for help moving. The professor reminded them how much they are looking forward to showing off their project to the public in the exhibit, but there is no paid staff to do all the things necessary to mount this public exhibit. So, it was in their interest to help make the exhibit a success, and in the week following the exhibit, the whole team spent the regular "capstone lab" time allocated in their schedule moving the exhibit back to the lab.

Monitoring and Guiding was mostly a VIP activity, although two of the capstone teams displayed a surprisingly high interest in helping make the exhibit successful, by dropping in voluntarily to check on operations and helping VIP students fix problems. Guiding involved greeting visitors to the exhibit, explaining what the exhibit is about, showing them how to do the gestures, and help them recognize the effects of their actions. Many students reported enjoying this activity as they watched visitors react to the exhibit. The project leader regrets not scheduling students to monitor the exhibit continuously during open hours, because things would break down and no one would know until someone showed up for some other reason.

Conclusion and Lessons Learned

Over the course of the project, the leaders identified several practices that led to problems and were modified and others that were beneficial and should be continued; these are listed in Table 6 and summarized below.

A public, multi-media interactive art exhibit was a very successful way to engage students of different ranks, disciplines, and modes. In retrospect, it was a great and unexpected blessing to have capstone and VIP sub teams working together, because the capstone teams often helped the VIP team with technical challenges that had to be overcome for everyone's projects to work in the exhibit, and the capstone teams were proud to have their products in the exhibit, yet the exhibit would not have been possible without the VIP team. The high school student and the undergraduate research students enriched the exhibit with their projects and being part of a team working towards an exciting goal was motivating for them. Many family members and friends of the students came to the exhibit and exclaimed to the instructors how much the students enjoyed being a part of the exhibit. One family of a capstone student drove four hours each way just to see the exhibit.

The students learned the importance of organization, documentation, teamwork, and clear and reliable communication with others. The students used design and project management techniques and team communication tools used in industry. The quiet and quick brainstorming and voting method that was used to determine the overall project concept worked very well. One capstone student said that this project experience was much like working within a team on his internship. For their Individual Final Videos, students were asked to give advice to new students, and most of them said the most important thing was to ask for help when you needed it. In many courses at Georgia Tech, students still tend to work by themselves. However, in this project, teamwork was necessary for the project to be successful.

Table 6. Summary of Lessons Learned in the *Raise Your Hand* project.

Lessons Learned	
Negative Experiences	
Description of experience	Proposed Corrective Actions
All sub-teams report orally in every class meeting left no time for informal communication between students	Only two sub-teams report orally in each class and the others post updates in a non-private Teams channel, leaving half the class period free for informal communication

VIP students distracted by devices in the class meeting	Only scribes use devices in the class and later combine and post their notes in Teams for other students' use
Sub-team presentations were inconsistent and difficult for student in other disciplines to follow	A concise presentation template, including a system block diagram in a particular format, required for sub-team oral reports
Students wrote late and superficially in their lab notebooks	Weekly due dates on electronic lab notebooks
Instructor disappointment that the first demos by VIP students were all using the students' laptops rather than lab computers	Future planning will have a first demo using student laptops and a separate motivation, such as an allocation of points to achieving networking of the student's project
Industry mentors underutilized	In the current semester, explaining to individual team members how the mentor can help them and encouraging both student and mentor to reach out to each other.
Positive Experiences	
Description of experience	Plan to Ensure Continuation In Future Projects
Capstone and VIP teams helping each other	Capstone proposals submitted regularly, especially before the semester of the exhibit, with overall project goals and special expectations clearly stated.
Project management and communication tools used in industry	Consolidate tools and allocate grade points to proper usage
Quiet and quick brainstorming and voting	Use at the start of each new project
Effective Team Dynamics activities	Always allocate time for this at about Week 4
Use of a common platform for all not explicitly grade-related communications for all project participants	Continue using Teams and Hello! and Response to Hello! assignments. However, consult with VIP sub-team leads to determine if platforms should be changed.
Non-disciplinary activities necessary to put on a public exhibit made for effect teambuilding across rank, mode, and disciplinary boundaries	Continue to hold public exhibits to show the work of the team.
Summer and undergraduate research students complement other groups' work	Continue to recruit summer students in areas of need for the project

The Effective Team Dynamics activities were helpful to the VIP students and instructors, especially the Five-Finger Pulse Check. These activities should not be overlooked for such a multi-disciplinary project, even though they take precious time.

The use of Teams for nearly all communications between project members regardless of mode and all but explicitly grade-related information from the instructors was an effective way to overcome rank, mode and disciplinary differences. Also helpful were the social and necessary activities of set building, moving the exhibit, assembling and disassembling it, and monitoring

and guiding during the exhibit; these activities contributed to students' sense of ownership of and pride in the exhibit and gave students the chance to learn to use power tools.

The project had some challenges that were mitigated with changes. Before the VIP class started using the standardized format for weekly updates, the updates took much longer and were not as informative. The format of the Main Meetings was changed to give the students much needed time to talk with each other. Instructor's fears that the students would leave early were not realized. The method of how students created Main Meeting Notes in their lab notebooks was changed to improve the quality of the notes and the student's engagement in the meetings. The lab notebook submission frequency was increased to allow earlier instructor feedback, improved student compliance, and quality of the notebooks.

There are still many opportunities to improve as the instructors and students begin working on the next exhibit, now scheduled for Fall 2024. A more cohesive instruction about the design process and better record keeping of the early design stages are needed. Students will naturally develop their projects first on their own laptops and integration of their projects into the exhibit network will need separate motivation. In Fall 2022, the motivation was the show, but it put excess pressure on the team. In the future, more time will be allocated and there will be a different motivation for integration. Although the industry mentors were able to give some good advice to the students, the instructors think the mentors were still underutilized and are searching for better ways to engage the students with the mentors. Tuning the allocation of points in the overall grade is an effective way to change the behavior of students, so the VIP instructors will continue working on this.

Despite the challenges, the authors strongly recommend this type of project to give students a valuable and rewarding interdisciplinary teamwork experience.

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