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Reinforcing Learning Objectives through Hands-on Labs for University of Michigan's ROB 204: Introduction to Human-Robot Systems

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Reinforcing Learning Objectives through Hands-on Labs for University of Michigan's ROB 204: Introduction to Human-Robot Systems

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Abstract

The University of Michigan Robotics program focuses on robotics as an embodied intelligence, where robots must sense, reason, act, and work with people to improve quality of life and productivity equitably across society. ROB 204 is an introductory course for robotics majors that provides a foundation for designing robotic systems to address a user need with a sociotechnical context. The course combines lectures, labs, and discussions to teach and reinforce learning objectives in an equitable and experiential manner. In this paper, we present the lab procedures, required materials, and reflections that operationalize concepts from lecture. Labs collectively include hardware, software, and stakeholder interactions to create emergent experiences for students that are only obtainable through active learning. Through the semester, students have lab themes around: (1) user interface control input design, (2) non-verbal human-robot communication, (3) human mental models and their interactions with robot hierarchical control levels, (4) stakeholder interviews and problem statement generation, and (5) concept design and usability testing. The hardware used within these labs spans paper prototypes, individual control elements (e.g., switches, potentiometers, encoders), customizable controllers for servomotor-based actions, and commercially-available robotic systems (e.g., Amazon Astro). The labs culminate in a holistic design process, centered on preparing students for community interactions. In our initial offerings of the course, we have brought in practicing nurses from hospitals to share real-world challenges and needs. Through these themes, system levels, and stakeholder interactions, students gain a foundational understanding of a socially-engaged design process in which they conduct quantitative and qualitative analyses to inform robot designs and evaluate their impact on society.

1 Introduction

The University of Michigan Robotics Undergraduate Program was launched in Fall 2022, building on the foundations of University of Michigan Engineering.[1] Michigan Robotics adheres to three core values:[*]

- **Robotics with respect**: We work to create a world where everyone is treated with dignity and respect, from our labmates to communities much different than our own. We need to ensure that our designs, programming, building, testing, and the function of our robots treat humans and human interactions with respect.
- **Enthusiastic outreach**: Through our community interactions, we inspire positive change in the world, informing responsible policy and accurate understanding of robotics.
- **Integrity in action**: Robotics has the leverage to shape our future, and it is important that we are honest, fair, and ethical, reporting our successes and failures as we create embodied intelligence.

Our undergraduate curriculum supports students in establishing these values through specific learning objectives. Robots are sociotechnical systems that interact with people and technology, so they require a design approach that considers both social and technical factors. The undergraduate program establishes Michigan Robotics values beginning with the gateway course, ROB 204: Introduction to Human-Robot systems, which introduces how stakeholders and human capabilities influence design decisions. ROB 204 shapes the undergraduate program for equity and engineering excellence.

ROB 204 combines technical skills and technical communication learning objectives to support students in building and communicating their understanding. Students are provided with frameworks to address the following technical questions:

- What process should we use to ideate robotic system designs?
- How can a person interact with a robotic system?
- How can characteristics of the users influence the requirements for a robotic system?
- How can we assess our design ideas with end users?

The course uses a Learn-Reinforce-Integrate approach. Students begin by learning new concepts and skills in interactive lectures, reinforce the technical concepts in labs, and then integrate the concepts through comprehensive assessments. Details on the course lecture topics were previously presented in Stirling et al. (2024)[2]. In this paper, we provide details on the labs that are used to support concept comprehension and intuition building.

2 ROB 204 Lab Descriptions

The lecture-discussion sessions introduce learning objectives aligned with a theme (Table 1), with labs designed to support these themes. The learning objectives follow Bloom's Taxonomy,

[*] https://robotics.umich.edu/about/values/

Table 1: Schedule of technical content and lab activity for ROB 204, adapted from Stirling et al.[2] for the Fall 2024 Semester

Week	Content	Lab Activity
1 – 2	Course Intro; Human Perception and User Interfaces	User interface design and evaluation
3 – 4	Human in the loop communication	Non-verbal Human-Robot Communication
5 – 6	Human Cognition (Mental Models; Situation Awareness; Trust)	Mental model building and robot hierarchical control
7 – 8	Socially Engaged Design	Stakeholder Interviews
9	Problem Statements, Needs Statements, and Requirements; Design ideation	Problem statement generation
10 – 11	Usability Studies	Robot concept design, Usability study design
12	Ethics; Risk assessment Presentations	Perform usability study
13 – 15	Final project work sessions	Iterate on design

introducing concepts to support remembering, understanding, and demonstrating (lower levels of the taxonomy) with the goal of enabling students to analyze, evaluate, and create (the top levels of the taxonomy).[3]

The set of labs during Weeks 1 – 6 were designed to build understanding of core human-robot interaction concepts, with the set of labs from Weeks 7 – 15 designed to build understanding of the socially-engaged design method.[4] Students have lab themes around: user interface control input design (Section 2.1), non-verbal human-robot communication (Section 2.2), human mental models and their interactions with robot hierarchical control levels (Section 2.3), and stakeholder interviews, problem statement generation, concept design, and usability testing (Section 2.4). In each lab description, information is provided on the overall learning objectives, hardware and software requirements, and lab protocol. Further documentation on each lab is provided at our public GitHub site.[†]

2.1 User Interface Control Input Design Labs (Week 1 – 2)

Well-designed user interfaces ensure intuitive and efficient communication between humans and robotic systems. A good interface enables users to complete their objectives while minimizing their cognitive load and their chance of making errors. This goal of intuitive interactions is especially important given the future concept of increasing use of robots in the home and during routine daily activities. In line with our core value of *robotics with respect*, user interface design decisions should be made with consideration for the needs and abilities of potential users.

2.1.1 Learning Objectives

The objectives of this lab are to equip students with the skills necessary to:

1. design and evaluate a user interface to support a robotic task,
2. implement different types of direct input controls for robotic systems, and
3. investigate the role of perception in interface design.

[†]`https://github.com/michiganrobotics/rob204`

These objectives are operationalized through the design and assessment of a physical user interface to control a simulated robotic arm that is based on the Japanese Experiment Module Remote Manipulator System on the International Space Station. The robotic manipulation task requires retrieving objects at precise locations and orientations in space and moving them to deposit zones. Students achieve the learning objectives by exploring:

1. Gestalt principles [5] to create visually effective and intuitive interfaces,
2. natural mappings [6] to align interface design with the user's mental model,
3. different input methods (e.g., buttons, switches, encoders), and
4. different control reference frames (e.g., independent joint control and end effector control).

By the end of this lab sequence, students have designed and critiqued a human-robot interface for the robotic arm simulator. Students submit reflections that include discussion of the physical interface devices (characteristics, pros, and cons), design principles that they used and that they observed other groups using, influence of human depth perception on performing the task, alignment of their mental model of the robotic arm with different interface solutions, and how this alignment affected the usability of the interfaces.

2.1.2 Hardware and Software Implementation

Hardware: The lab is performed using a kit of electrical parts ("peripherals") that allow students to create their own human interface device for a desktop computer (Fig. 1). An Arduino interprets the signals from the assembled input device and sends inputs via USB to the connected computer. Each group is given an Arduino and the following peripherals: rotary encoders, linear potentiometers, switches, and buttons. These peripherals were encased in 3D printed housings with Velcro attached to the bottom. A piece of felt attached to a board was provided so the students could position the peripherals freely.

Software: The lab is performed on a browser-based robotic arm simulator[‡] that displays a re-creation of the International Space Station and allows configurable control over a simulated robotic arm, modeled after the Japanese Experiment Module Remote Manipulator System (Fig. 2). The simulator features:

- **Viewpoints**: Three camera views providing an end-effector mounted camera, a stationary camera pointing at the robotic arm, and a controllable camera which can be panned left and right.
- **UI mappings** A controls menu that allows students to customize their control bindings or toggle between two different control schemes.
- **Manipulation task**: A timed pick-and-place task where objects are randomly positioned in space with a specific grasp location and destination.

[‡] `https://websites.umich.edu/~rob204labs/`

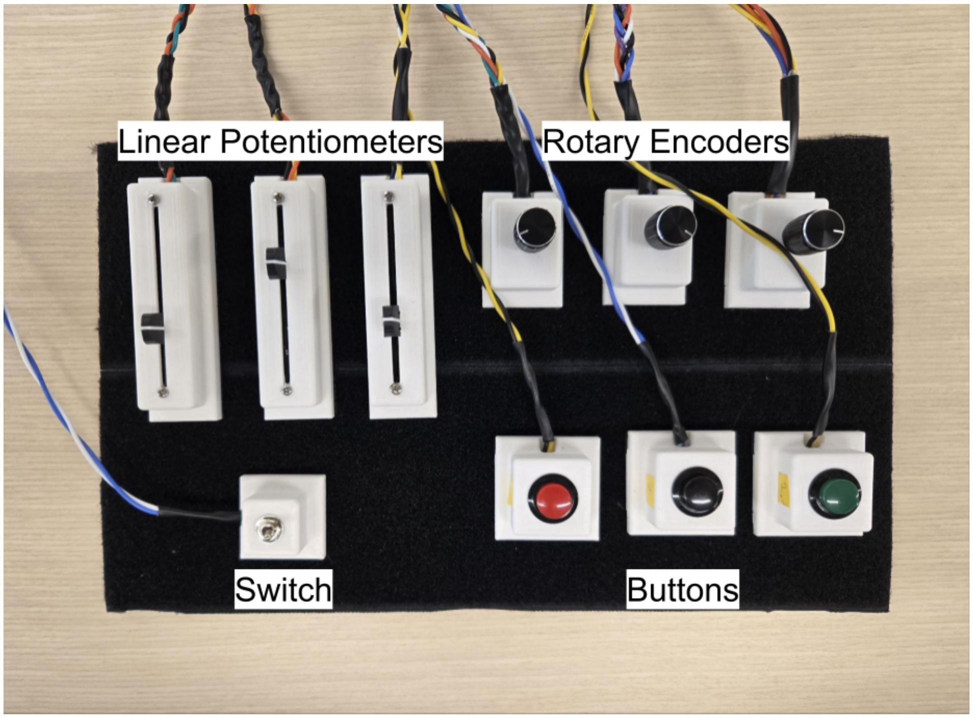


Figure 1: Labeled photograph of the human interface device students used to control the simulator. Students assigned these controls to the different functions of the robotic arm.

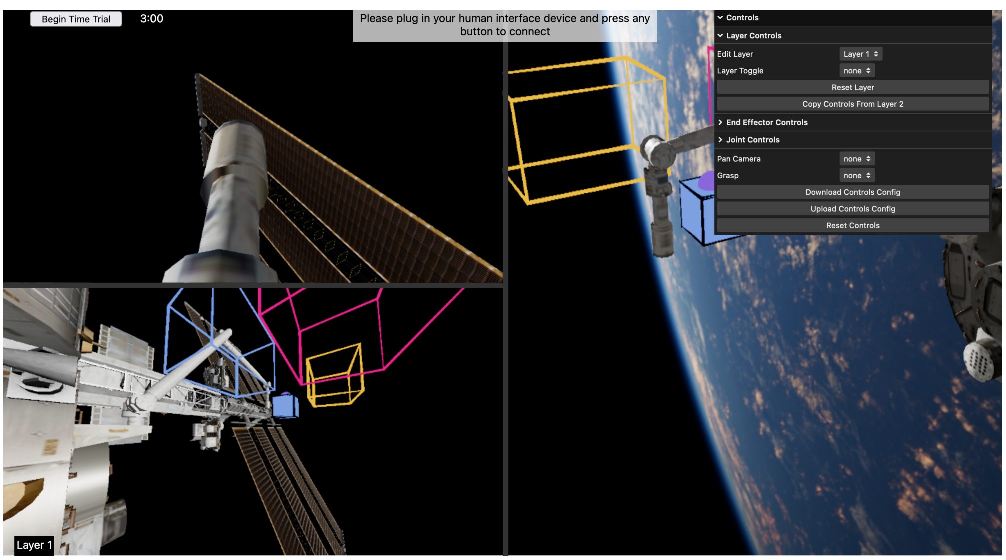


Figure 2: Screenshot of the browser-based robotic arm simulator. Students position the end effector of the arm over the spherical grasp point on the colored box and move it to the rectangular area of the corresponding color.

2.1.3 Lab Protocol

This lab was performed over two sessions. Session 1 focused on interface design and Session 2 focused on evaluation and reflection. During Session 1, small groups of 3–4 students would create a physical control interface. Students design this interface by attaching the peripherals to a board using hook-and-loop tape. This process allows students to position and orient their chosen peripherals in any way that they like. Students were also free to assign their peripherals to the robotic arm controls. They could choose between controlling joints independently and controlling the position of the arm's end effector. They could also assign a button or switch to toggle between two different sets of control assignments, allowing each peripheral to perform up to two different functions. They were instructed to apply Gestalt and natural mapping principles in their design and reflect on how they applied these principles. During Session 2, students evaluated their interfaces by using them to control the robotic arm in the pick-and-place task. The students used their own designs and then rotated to other groups to evaluate additional interface solutions. They were instructed to reflect on the similarities and differences in interface design between solutions, considering the learnability of the other interfaces and user interface design principles.

2.2 Non-verbal Human-Robot Communication Labs (Week 3 – 4)

Robots and robot systems that work with or operate near humans will invariably need to communicate with those humans. While students can quickly understand verbal human-robot communication needs due to its strong parallels with human conversation, teaching non-verbal human-robot communication requires illustrating and identifying signaling behaviors that may be subtle or overlooked. For weeks 3 and 4 of class, the lab activity focuses on non-verbal human-robot communication and the design of an interface to influence the robot state.

2.2.1 Learning Objectives

The objectives of this lab sequence are to:

1. implement a posture-based non-verbal communication pipeline to control a robot,
2. compare and contrast the effect of adding robot control states on the system usability,
3. critique design decisions for a non-verbal communication strategy, and
4. identify alternate non-verbal communication design ideas to support human-robot communication usability.

These objectives are operationalized through an activity in which students implement a posture-based non-verbal communication pipeline to control a robot embodiment. The base setup for the lab maps a student's head movement (right, left, and center) to the motion of a robotic arm. The arm then points to corresponding Morse code symbols and allows for other students to decode a message without the use of words (Fig. 3). While students are in the same room for this lab, the motivating scenario is that a human team may be in different locations, with a loss of verbal communication capability between the locations. What is available is a camera at one location that can can be used to create movement of the robot at the other location.[§] Through this non-verbal pathway, students enable information to be communicated to team members at the location with the robot by the team member at the site with the camera. Students are asked to critique the initial setup, identifying limitations of the selected non-verbal communication

[§]This scenario was inspired by the communication limitations in the novel, The Martian by Andy Weir.

strategy. Lastly, students are asked to modify this setup to suit the needs of a more complicated message, experimenting with new ideas and discussing the use cases of this type of robotic system. At the end of the lab sequence, the students have learned to use robot gestures for communication of words and how adjusting the robot gesture settings (e.g., number of symbols, size of movements, etc.) alters the effectiveness of this communication.

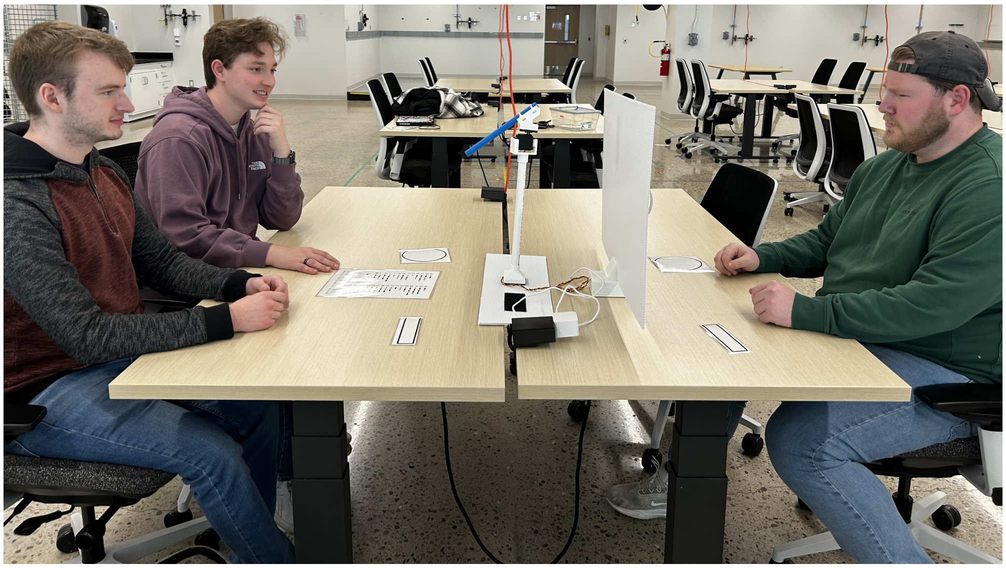


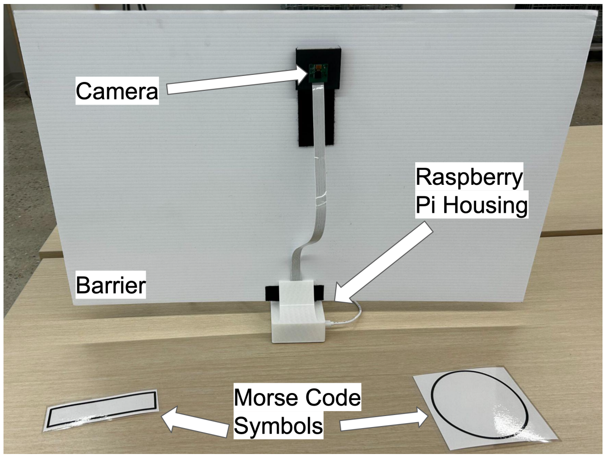
Figure 3: Layout of non-verbal communication setup. The right side shows the user whose head posture is being tracked to inform movement of the robotic arm. The left side shows the students who will decode the robot arm behavior into the intended message.

2.2.2 Hardware and Software Implementation

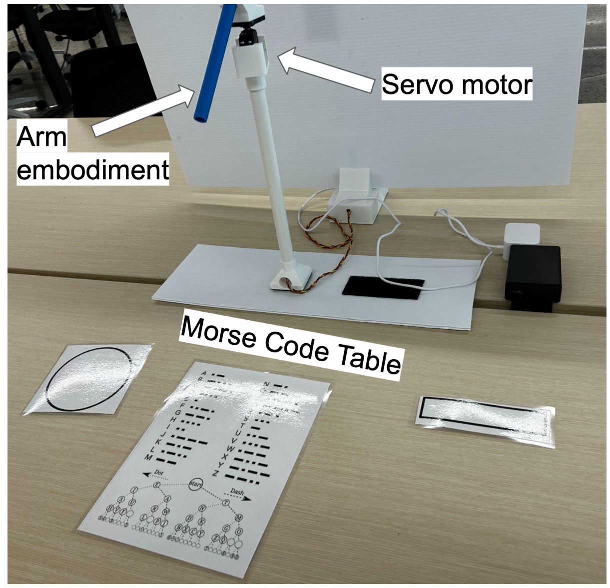
Hardware: This lab uses a Raspberry Pi to interface with a camera and servo motor to perform the tasks of the lab. 3D printed components and PVC pipe house the majority of the hardware necessary for the lab. The setup for the lab uses a piece of corrugated plastic to create a barrier between the student communicating the information and the students decoding the message. Morse code symbols are printed to facilitate the user experience in interpreting the mapping of the robotic arm position to the Morse code symbol and allow timely decoding during communication attempts (Fig. 4).

Software: Software on the Raspberry Pi uses Google AI Edge MediaPipe's Vision Face Landmarker to identify and track facial landmarks in real-time. The software processes the live video feed from the camera to detect and analyze the position and orientation of the user's face. Based on these data, the system computes the user's head orientation, which is then mapped to specific angles. These angles control the servo motor, moving the robotic arm to one of three predefined positions. The exact code used can be viewed on the GitHub.¶ Students edit the code using a Jupyter Notebook to add more servo positions within the lab.

¶https://github.com/michiganrobotics/rob204



(a)



(b)

Figure 4: Detailed view of lab setup. (a) User side showing the camera used for head tracking, housing compartment containing the Raspberry Pi, and Morse code symbols. (b) Receiver side, showing the robot arm embodiment used to point at morse code symbols.

2.2.3 Lab Protocol

This lab is performed over two sessions. Session 1 begins with a preliminary phase which allows students to familiarize themselves with the hardware and communication scheme. Students experiment with the embodiment in an unstructured manner, ensuring they understand how quickly the motor responds to head movements and removing possible confusion associated with which direction (left or right) is associated with which Morse code symbol (dot or dash). After this stage, students are asked to design a set of guidelines for communication, including, but not limited to, how to repeat a symbol, indicate a new letter, and communicate when the word is done. Students are not permitted to speak with the user of the robot arm, so emphasis is placed on brainstorming edge cases that may arise during the activity.

Once these guidelines have been documented, each student takes a turn behind the screen to attempt to communicate a word. Selected words vary in length from three to ten letters, and students are given four random words to choose from for this activity, generated using a random word generator site. After a word has been communicated, students take note of whether they were successful in their decoding. This process repeats until every group member has had an opportunity to try the robot. Session 1 ends with a reflection on the activity of the lab. Students consider the success of their defined communication scheme and any emergent challenges, discuss scenarios where this specific embodiment may be useful, comment on other communication channels that may have been present during the activity (e.g., hearing the movement of the servo motor), and ideate ways to improve the current embodiment.

In Session 2, the non-verbal communication task difficulty is increased by shifting from communicating Morse code to communicating a minimum four-character alphanumeric sequence, randomly generated by a website. Students must update the software algorithm controlling the robot arm to increase the number of states allowing for more possible outputs, as well as design an updated communication scheme. This task requires more precise head movements, making communication more complex and requiring students to consider both the technical aspects of handling more states and the usability of the provided robot embodiment. The lab concludes with a comparative discussion, where groups evaluate the efficiency and user experience of their strategy against Morse code, and reflect on the design process needed when balancing states and gains.

2.3 Human Mental Models and Robot Hierarchical Control Labs (Week 5 – 6)

The usability of a robot is influenced by a user's mental model of the system, which includes the purpose, form, function, and expected behavior of the system.[7] User trust is calibrated through comparisons and updates of their system mental model and the system's observed capabilities and performance. The system's design can support or weaken a user's trust in the system for specific tasks. One approach to consider the role of the human in these interactions is hierarchical control, which decomposes tasks into sub-tasks with algorithms designed to support human-input at differing hierarchical levels (e.g., high level is aligned with a user mode selection related to tasks that could be performed, mid level is aligned with the user defining parameters within the task, and low level is aligned with the user directly informing the underlying actuator control). The alignment of the user input to the system capabilities and the user's mental model influences system usability. This set of labs provides students an opportunity to develop a mental model for the Amazon Astro and develop an understanding of its capabilities at different levels of control. These labs support the values of *integrity in action* as students develop understanding of what a specific robot embodiment can and cannot perform and how to communicate these successes and failures to support users gaining a calibrated trust of how systems should be used.

2.3.1 Learning Objectives

The objectives of this lab are to:

1. develop a mental model of a robotic system and evaluate it,
2. describe the importance of calibrated trust in automated systems,
3. compare and contrast operating a robot at different levels of control, and
4. evaluate when certain levels of control are more appropriate than others.

In Week 5, these objectives are operationalized through a performance assessment of the home robot Amazon Astro in a standardized test environment. Students are given a brief introduction to the robot, its intended purpose, and are tasked with evaluating their mental model of the robot's capabilities. Students achieve the learning objectives by completing tasks with Astro in varying levels of difficulty. In Week 6, students are tasked with completing various tasks using Astro's different input types.

At the end of the lab sequence, students have developed and evaluated a mental model of Astro. They have also experienced controlling Astro at different control levels to accomplish tasks.

Students submit both qualitative and quantitative information about their evaluation of the design of Astro's human-robot interaction.

2.3.2 Hardware and Software Implementation

This lab makes use of a commercial home robot called Amazon Astro (Amazon, Seattle, WA). This robot was designed to perform tasks such as delivering objects placed in its container throughout the house, answering questions, and monitoring the home. The screen on top of the robot's body displays two eyes resembling a cartoon character, which change to show different emotions based on the robot's actions. These features allow the robot to express emotions through its animated eyes with subtle visual cues.

The Astro robot operates using commercial software algorithms to navigate a home environment and respond to user requests. Visual simultaneous localization and mapping (V-SLAM) is implemented to both process and respond to visual input data collected by the robot's sensors. The robot can be commanded to travel to different locations using varying levels of automation. High-level control is enabled via voice commands, mid-level control is enabled via tapping the end location to which the user wants the robot to travel within the Amazon Astro app, and low-level control is enabled via keypad directional control also found in the app. All three of these modes are used in this lab to convey design decisions for human-robot interaction in the context of levels of control and task expectations.

2.3.3 Lab Protocol

This lab is split into two sessions, with the first session exploring trust and the second session exploring levels of control. The first session begins with initializing the Astro setup, which is a simplified home environment with two rooms (Fig. 5). The students instruct the robot to map its new environment and label each room. These tasks can be accomplished using the commands "start exploring" and "start home tour," respectively. Students are then asked to rate their trust in the robot performing a set of tasks such as "come here" and "follow me" using a trust scale and record their predictions. The trust scale used is a 5-point ordinal scale with anchors provided (1-Completely distrust, 2-Somewhat distrust, 3-Neutral, 4-Somewhat trust, 5-Completely trust). These steps are repeated for two alternate environments (one with small obstacles, and another with backpacks as obstacles). After recording predictions for these tasks, the students instruct Astro to perform each of the tasks via voice commands. For each of these tasks, students provide an updated trust score based on their observations of the robot's performance. These before and after data are then used to create a bar chart to support graphical communication skills. Students reflect on Astro's performance compared to their mental model for the robot and reflect on the concept of calibrated trust in context with automated systems.

The second session of this lab extends concepts studied in the first session with levels of control and dimensions of workload[8] (e.g., mental demand, temporal demand, and frustration). Students instruct Astro to perform tasks at each of the 3 levels of control and provide their perceptions of mental demand, temporal demand, and frustration according to how Astro performed each task. The students reflect on which level of control aligned with each task and why they had those perceptions. These responses challenge students to think about the pros and cons of each level of control and how they can vary by the type of task and the capabilities of the system. The final set of reflection questions propose hypothetical scenarios and ask students to use their observations to predict how well they think Astro would perform in an actual home environment.

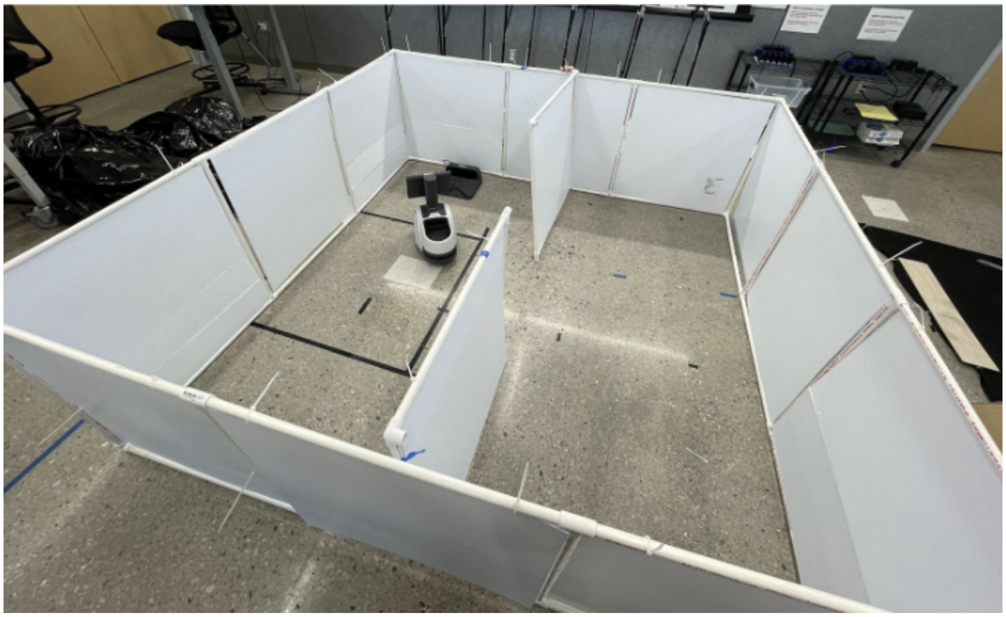


Figure 5: The simplified Astro home environment setup. Walls were designed to be high enough to be accurately mapped by the proprietary Amazon Astro perception stack. Internal walls separate the environment to create rooms.

2.4 Stakeholder Interaction-Informed Robot Conceptual Design Labs (Week 7 – 14)

The design and deployment of a robot can be considered through multiple lenses, including feasibility (do we have the technology to make the system), desireability (is it something that people would value), and viability (does the system create business value). Our sociotechnical approach to ROB 204 emphasizes the desireability lens by providing students practice using the socially-engaged design process.[4] This approach aligns with Michigan Robotics values of *robotics with respect* by teaching students how to engage with communities to make sure designs are addressing diverse needs and can be used by the communities for which they are designed.

2.4.1 Learning Objectives

The objectives of these labs are to:

1. design and evaluate open-ended questions to engage with stakeholder perceptions,
2. demonstrate active listening skills to support understanding a diversity of stakeholders,
3. use interview data to write a problem statement and needs statements,
4. define solution neutral system design requirements that will inform the design solution,

5. apply design ideation methods to support robotics design concept development,
6. create storyboards to support understanding the human-robot interactions within the task,
7. design and implement a usability study to assess a system, and
8. evaluate usability study outcomes to inform system design iterations.

These objectives are operationalized by selecting a stakeholder group to interview and going through initial iterations of the socially-engaged design process. In our initial offerings of the course, we brought in practicing nurses from hospitals to share real-world challenges and needs. However, the same process can be applied for alternate stakeholders and future iterations of the course will expand to other opportunities where robotic solutions may be relevant, including supporting aging in place, agriculture, and hospitality.

By the end of the lab sequence, students had conducted an interview, defined a problem, ideated a conceptual design, performed a usability study, and iterated on their designs. Students' lab reports include:

- **Stakeholder Interviews**: Questions to elicit storytelling; reflection on the stakeholders' job, the technology they use, what they find most rewarding, and what they find most challenging; student perspective on opportunities for robots and concerns about integrating robots into the work setting
- **Defining Problem and Need Statements**: Emergent themes that align with needs and requirements, definition of functional and non-functional requirements that align with a selected need, generation of a problem statement that meets defined criteria
- **Design Ideation**: Design concepts based on brainstorming, morphological analysis, and heuristic ideation; mapping design concepts to requirements, storyboarding concepts
- **Usability Study**: Justification for selected tasks, diagrams and sketches of the concept to support the study, operationalization of usability concepts, study timeline
- **Design Iteration**: Usability study analysis (direct measures and user perceptions), updated design iteration, risk considerations

2.4.2 Hardware and Software Implementation

While no hardware or software is required for this lab sequence, students are welcome to implement concepts for their usability study in different manners. Students were discouraged from building functioning prototypes, but were encouraged to have simplified sketches and mock-ups to enable early-stage design iterations. For their usability testing, student concepts ranged from sketches to computer-aided design models and simplified software mock-ups.

2.4.3 Lab Protocol

This lab sequence is performed across seven sessions: (1) defining questions for stakeholder interviews, (2) conducting the stakeholder interview, (3) defining problem statements from the interview findings, (4) design ideation, (5) designing the usability study, (6) conducting the usability study, and (7) design iteration.

Stakeholder Interviews: In the first session, students are placed in teams to design questions for the stakeholder interview. The goal of their questions is to promote an understanding of a work shift, including the tasks the stakeholder takes on, the types of technologies they use for their job, the challenges they face, and parts of the job they enjoy. Students tested questions during this session with peers to assess question clarity and whether their questions were respectful, open-ended, non-leading, and supported narrative responses. In the second session, students interview nurses in teams. We aim to have each student team speak with three different nurses, for approximately 20 minutes each.

Defining Problem Statements and Design Ideation: In the third session, students define needs based on their interviews, where the needs must be solution-neutral, balance breadth and specificity, and describe measurable outcome metrics. Project teams are constructed during this session based on mutual interest in an emergent need and are maintained for the rest of the sessions. Student teams select two needs statements and write functional and non-functional requirements[9] that align with their selected needs. Functional requirements specify what the system must do and were framed as “The system shall...” or the “The user shall...”. Non-functional requirements specify qualities the system must have and were framed as “The solution shall...”. Students then construct a problem statement that provides the context for the selected challenge, the needs they would address, and the requirements that should be met.

In the fourth session, students apply design ideation methods[10] using their problem statement as a starting point to create conceptual designs and task flows that address the defined needs. Students start with a general individual brainstorm approach, then work together to apply a morphological analysis where solutions are generated by breaking the problem into functions and exploring solutions for each function. The morphological analysis encourages additional specificity in their design as it encourages thinking about different functional needs within the task that can be missed in open brainstorming. Students then use design heuristic prompts to further extend solution ideas. Finally, students implement a storyboard for one of their concepts to encourage additional formalization details on the human-robot interactions.

Usability Study: In the fifth session, student teams design their usability study. The storyboards from the previous session are used to select tasks that align with the needs and are also appropriate for a conceptual phase study that uses a think-aloud testing method. In a think-aloud approach, the task prompt is provided and the user narrates their responses of what they would do in context with a provided concept. To enable detailed user responses, students develop detailed concept sketches or simplified mock-ups to support the study. Student teams also select from a list of usability concepts presented in lecture to operationalize for their usability study. Students are instructed to select measureable attributes that align with an early conceptual analysis. Teams create their protocols, with the goal of the study being around 20 minutes. Protocols include questions to collect relevant demographic data on the stakeholder, procedures for the think-aloud tasks (and the associated training materials to support these tasks), and post-task survey questions to elicit additional feedback on their conceptual designs. The student teams then practice their procedures with other teams.

In the sixth session, students perform the usability study with nurses. Similar to the interview session, student teams had the opportunity to run their usability study with three different nurses, for approximately 20 minutes each.

In the seventh session, students analyze the usability study data and use this information to iterate on their designs. From the demographic data, teams articulate who was included, but also what types of stakeholders were missing. From the think-aloud data, teams describe any misconceptions users had, incorrect actions that were taken, and comments users made on the operation of the system. Teams tabulate their usability attributes and reflect on their specific metrics. From this analysis, students iterate on their design, connecting how design changes align with the usability study findings. The updated design also requires student teams to discuss risks that could emerge from the design and how they could be mitigated.

3 Discussion

The University of Michigan Robotics program focuses on robotics as an embodied intelligence, where robots must sense, reason, act, and work with people to improve quality of life and productivity equitably across society. ROB 204 is an introductory course for robotics majors that provides a foundation for designing robotic systems to address a user need with a sociotechnical context. The course combines lectures, labs, and discussions to teach and reinforce learning objectives in an equitable and experiential manner. In this paper, we present the lab procedures, required materials, and reflections that implement concepts from lecture. The set of labs during Weeks 1 – 6 were designed to build understanding of core human-robot interaction concepts, with the set of labs from Weeks 7 – 15 designed to build understanding of the socially-engaged design methods.

Within the course, students are provided frameworks to support ideating robotic systems, approaches to interact with a robotic system, how user characteristics can inform requirements and how designs can be assessed. End-of-semester course evaluations emphasized the importance of labs in teaching the concepts. One student succinctly commented that "*The entire idea behind how to design a system was something I never really thought about when building things. I would just go in hands–first, building first and thinking later. This course has taught me the importance of a proper design phase and how you can improve the quality and usefulness of a product by design.*" Many students stated that the labs were the most valuable aspect of the course. An example comment from a student was that they "*feel that the labs are a great practice of the concepts that we are learning in class and the reflection assignments are a real–life application of the concepts as well.*" Students directly referenced the final lab sequence, with comments including that "*Talking to nurses/stakeholders – through interviews and usability studies – and designing a robotic system were very valuable*" and noting "*the final project which is nothing short of amazing*." Another student noted the lab sequence "*was very helpful in teaching me the importance of understanding the needs of the end–users and how the design process should be done*." One student noted that "*the situations we are considering are making me more mindful of design choices in my project teams and other classes*."

However, student feedback also highlighted challenges and opportunities for continued improvements. The integration of hardware into the labs creates failure opportunities. In the User

Interface lab and Non-verbal Human-Robot Communication lab, there were times when wires became disconnected, leading to a loss of communication. During the Human-Robot Communication lab, students could make changes in the software that led to errors in the run-time operations. There are learning opportunities for distinguishing between concept errors, hardware errors, and software errors that could be exploited to further support learning when embodied systems are used. Some students also commented that while the active lab portions were helpful, the "*tedious writing was the least valuable*." The write-ups for each lab required reflecting on provided prompts and several students expressed being frustrated with the writing. However, technical communication is an important part of an engineering education. While we can iterate to remove potential repetition across questions, the act of expressing understanding through writing should be maintained even though students may not initially appreciate the process.

A particular challenge for ROB 204 is its focus on design theory rather than design construction. Amidst the background of project-driven and prototyping-heavy courses in the Michigan Engineering curriculum, some students express disappointment that they created mock-ups for usability studies rather than functional robots. One student noted "*there should have been more of an emphasis on actually building something*." This perspective reflects the goals and desires of many robotics students—they are eager to build, explore, and iterate. We actively encourage these activities across the Robotics curriculum, with emphasis in ROB 204 on design theory principles that can be applied in a design-independent manner. As part of our course introduction, we explain the importance of following a design process and include many recent and historical examples throughout the course lectures. However, these examples may appear academic. Continued integration of relevant case studies in future class offerings that highlight different choices will help students see how hasty and misinformed designs perform poorly. Inclusion of guest lectures from those in industry can also reinforce the benefits of designing first before jumping into the building phase.

While evaluations help us understand student perspectives within the term, they do not reflect perspectives that may be gained in the future. It is sometimes several semesters or years later that students can make new connections and realize value they did not appreciate at the time of a course. This lag is especially important for ROB 204 since subsequent courses in our Robotics curriculum provide ample opportunities for application and reflection. It will be important going forward to gain student insights during their exit surveys and as alumni to the program.

Based on our experiences, we recommend the following practices for implementation of courses like ROB 204.

- Create robust and duplicate lab kits to mitigate inevitable hardware failures for hands-on labs.
- Create key concept documentation for teaching staff to support consistency across instructors.
- Thoroughly motivate and frame the course in the initial lectures so that students understand the emphasis on design theory and technical writing.
- Integrate case studies within lecture and map them to student experiences within lab.
- Track student perceptions of the course longitudinally throughout the degree program.

Accessibility of these labs from a financial lens is important to consider. While the majority of our labs use inexpensive materials that can be easily procured, the robot embodiment selected for Week 5 – 6 may not be feasible for many programs to use. However, the concepts within that lab could be mapped to other robot embodiments, such as the MBot[‖] platform, in the future. The concepts in the labs are hardware independent, but operationalized within these labs to support active learning. Accessibility can also be considered from the viewpoint of the ability of the software to be useable for all students. We observed that the off-the-shelf face tracking software we included did not efficiently track all skin tones. While this limitation was a learning moment for students about accessibility and equity in commercially available systems, it is an opportunity for improvement in the software implemented in the lab.

4 Conclusion

ROB 204 is an introductory course for robotics majors that provides a foundation for designing robotic systems to address a user need with a sociotechnical context. In this paper, we presented the lab procedures, required materials, and reflections that operationalize concepts from lecture. Labs collectively include hardware, software, and stakeholder interactions to create emergent experiences for students that are only obtainable through active learning. While many students perceived the labs as supporting their understanding of key concepts, the importance of stakeholder engagement, and the benefit of iterating design ideas before prototyping, there were some that reported frustration that they did not have more immediate technical applications of these concepts within the final lab sequence. Continued integration of robotic case studies within lectures that are connected to the students' lab experiences will support teaching the importance of the conceptual design phase as part of a socially-engaged design process that aligns with the core values of the Robotics program.

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