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Lessons Learned in Developing ROS Asynchronous Tutorials for Robotics course: Guided versus Inquiry based Learning

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Lessons Learned in Developing ROS Asynchronous Tutorials for Robotics course: Guided versus Inquiry based Learning

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Abstract

Robotics is a highly multidisciplinary area of study, with introduction to robotics taking many forms at different universities[1, 2, 3, 4]. ROS (Robot Operating System), a middleware package used in physical and simulated robotic systems and sensors is often used in robotics curriculum to prepare students for the many robotics industry positions and research careers that utilize this middleware [5]. Learning ROS can at times be non-intuitive and overwhelming for students[1]. Limited online resources exist to help students learn ROS asynchronously[6], and none have studied how students perceived self-efficacy in tackling future robotics project challenges.

Asynchronous tutorials help students learn material that would take too much time to step through in class, enhancing the principles taught. They can help students troubleshoot specific issues they run into, allow students to go at their own pace, and allow flexibility in how students approach different challenges. In this Introduction to Robotics course, over three years, tutorials to learn ROS have been part of homework assignments and now part of lab sections (for more in-person assistance). These tutorials and challenges of the midterm and final project aim to rapidly form the foundational skills and knowledge to use ROS in both simple exercises and establish self-efficacy of students in tackling future robotics projects.

The challenge when designing and implementing these tutorials is how much guidance to provide. These tutorials began as extensions of ROS tutorials provided by Open Robotics (a nonprofit that updates and maintains ROS), but over three years have developed into highly structured labs, with more step-by-step guidance. Throughout this evolution, we have collected (and are collecting), with IRB, subjective and objective measures of robotics interest and self-efficacy.

This paper discusses the student feedback, student performance, and practical benefits and limitations of these different levels of guidance for learning ROS and for tutorial development in general. Lessons learned will be discussed including: pitfalls in developing inquiry based learning tools, types of asynchronous support needed with different levels of guidance, perceptions of student performance benefits versus self-efficacy development, and advice when developing sequential tutorials for learners with different educational backgrounds. These will be discussed in the specific contexts of the last three years of these tutorial's evolution, emphasizing the pros/cons of each method.

Introduction

Hands-on experiences are essential in engineering education, particularly in fields like robotics that demand both theoretical knowledge and practical skills[1, 6]. Over the past two years (2022 and 2023), an introductory robotics course was taught without structured lab sessions, limiting opportunities for students to directly apply concepts to asynchronous tutorials. Observations from this period suggested a gap between students' theoretical understanding and their ability to tackle real-world robotics problems with ROS[7].

To address this gap, a comprehensive lab sequence was introduced in 2024. Nine progressively challenging labs were implemented to scaffold learning—from basic Linux and Git workflows to advanced tasks such as mapping, exploration, and multipart manipulation with robotic arms. These labs were designed to strengthen core competencies in programming, ROS2 (Robot Operating System)[8], and robot simulation, ultimately preparing students for an open-ended final project that encouraged creativity and deeper exploration.

Early indicators from the new lab structure revealed marked improvements in student engagement, preparedness, and confidence. Both quantitative survey data and qualitative feedback pointed to a stronger foundation in robotics fundamentals, a heightened sense of accomplishment, and more ambitious final projects. This paper aims to detail the motivation behind the course redesign, outline the development and implementation of the lab sequence, and provide an analysis of its impact on student outcomes. The findings reinforce the value of progressive, hands-on activities in bridging the gap between theory and application in robotics education.

Background

Guided versus Inquiry Based Learning

When learning a new subject, there is an important balance between guided and inquiry based learning. Examples of guided learning include lectures, recipes, and step-by-step guides. This process can be particularly helpful when learning a complex topic by reducing cognitive load and ensuring that students stay on track toward specific learning outcomes[9]. By contrast, inquiry based learning requires students to actively engage in learning by exploring problems, questions, and discover solutions collaboratively with other students or even independently.[10] This learning style can promote deeper understanding through active engagement. Although inquiry based learning has grown in popularity, when and how to incorporate into the learning cycle (and with what level of guidance) is still debated.[11, 9]

Motivation

Challenges in Previous Course Iterations

In earlier versions of the course, many undergraduates had minimal direct engagement with robotics systems, especially if their final projects did not require physical hardware. As a result, core topics—such as Motion Planning, Perception, and Manipulation—remained abstract, causing students' interest in these areas to plateau by semester's end. Another concern stemmed from heavily prescriptive tutorials that emphasized guided learning, where students followed step-by-step instructions without gaining deeper conceptual understanding or problem-solving skills. Those who relied on these "copy-paste" approaches frequently reported feeling underprepared for the more open-ended elements of the course.

Additionally, the absence of structured, guided lab exercises contributed to a gap between theoretical discussions and real or simulated applications. While students had exposure to Linux, Git, and ROS, they were left largely on their own to integrate these tools into final robotics tasks. For advanced challenges like sensor integration, robotic arm manipulation, and path planning, this lack of formal support often proved overwhelming, reinforcing a reliance on surface-level knowledge rather than building robust competencies.

Importance of Progressive, Hands-on Learning

In response to these limitations, the course underwent a major redesign in 2024, introducing a sequence of nine labs that systematically tackled the shortcomings in engagement, skill mastery, and applied learning. Each lab was designed to bridge theory and practice by translating key robotics concepts into hands-on exercises. Rather than limiting students to abstract theory, the labs encouraged them to see firsthand how various principles—ranging from ROS2 node interactions to navigation and manipulation—could be applied in simulation environments.

Another central aim was to foster skill mastery and confidence in ROS2 by gradually scaling the complexity of tasks and slowly incorporating more inquiry based learning. Students began with foundational activities, such as familiarizing themselves with command-line operations and basic Git workflows, before advancing to more demanding challenges involving multi-step manipulation or map-based navigation. By layering each new topic onto a solid framework of earlier lessons, the course sought to reduce intimidation, enable incremental learning, and help students retain crucial knowledge for subsequent labs.

Finally, the lab series was intended to encourage autonomy and creativity. Over time, the exercises shifted from highly guided tutorials toward more exploratory assignments, culminating in a final project where students chose their own goals. This structure allowed learners to transform rote procedures into practical skills, ultimately feeling more comfortable with robotics experimentation by the semester's end.

Course and Lab Design

Course Overview

This introductory robotics course is conducted over a single semester of approximately fourteen to fifteen weeks, enrolling primarily Mechanical Engineering majors who often have limited background in software-focused tools. The overall assessment structure consists of a midterm examination, which has remained largely unchanged from earlier iterations, followed by a final group project in which students select a robotics topic or application of interest. This dual format balances theoretical grounding with practical exploration, allowing teams to pursue specialized domains based on their collective strengths and ambitions.

Lab Sequence Design

In 2024, the course introduced a sequence of nine progressively challenging labs[**?**] aimed at cultivating both foundational and advanced competencies. Students began with Lab 1, which covered Linux and Git basics, ensuring they had the command-line skills and version control knowledge necessary to tackle more complex assignments. In Lab 2, they delved into ROS2 fundamentals by exploring nodes, topics, messages, and various command-line tools, setting the stage for deeper projects in later labs.

Moving into Lab 3, students used Turtlesim to draw their initials, reinforcing basic ROS2 commands while encouraging creative problem-solving beyond step-by-step tutorials. Lab 4 pushed these concepts further by having students build custom publisher-subscriber scripts, sharpening their understanding of how ROS2 components exchange real-time data. This trajectory continued in Lab 5, which introduced the UR5e robot arm and Robotiq 2F-85 gripper in a simulated environment. Through hands-on manipulation of the Unified Robot Description Format (URDF), learners not only practiced higher-level ROS2 control techniques but also recognized parallels between simulated robotics tasks and potential real-world operations.

The complexity of assignments increased significantly in Lab 6, where students programmed pick-and-place routines to stack three blocks in Gazebo. Notably, the midterm exam occurred around this point, but despite the midterm remaining unchanged from previous years, many participants perceived it to be simpler than Lab 6's multi-step challenges—a testament to their improved preparedness. Lab 7 marked a shift to mobile robotics as learners teleoperated a TurtleBot 4 in a maze, introducing sensor data interpretation and basic navigation strategies. Building on that, Lab 8 asked them to write an exploration script for autonomous movement, requiring further integration of sensor feedback and more advanced navigation logic.

Finally, Lab 9 culminated in the implementation of the A* search algorithm to identify optimal exploration points and complete a full map of the environment. This exercise combined concepts from earlier labs, highlighting advanced path planning and perception skills as students formulated cohesive solutions that integrated multiple ROS2 packages. By the time they reached this final assignment, most learners had developed a solid framework of fundamental competencies that could be extended to their final, open-ended projects.

Rationale for Key Changes

From the outset, the lab sequence was devised with progressive complexity in mind, gradually layering new tools and concepts to reduce cognitive overload. This scaffolded approach helped students steadily build confidence, ensuring each new skill—such as command-line proficiency or ROS2 control—was reinforced before introducing more demanding tasks. Additionally, hands-on integration with simulated environments and (for some students) real hardware reflected how robotics is typically approached in research and industry, where simulations validate concepts before being transferred to physical systems. Although not all undergraduates in this course interacted with physical robots, master's-level students were required to do so, underscoring the course's emphasis on bridging the gap between theory, simulation, and tangible experimentation.

Lastly, the inclusion of open-ended final projects further stimulated engagement and creativity. By allowing student teams to select topics aligned with their interests, the course encouraged independent exploration and deepened motivation. Through these projects, learners could apply the cumulative skills developed in the labs to design novel solutions, demonstrating a solid understanding of robotics principles and the confidence to innovate beyond prescribed tasks.

Methods

To assess the impact of the newly introduced lab sequence, a comprehensive survey was administered at three points during the semester—in the first week of class, around midterm (Weeks 7–8) and again at the course's conclusion (Weeks 14–15) through IRB Protocol:[anon]. Although numerous questions were included, the analysis here focuses on those most pertinent to student engagement and competency. First, students rated their interest in fundamental robotics domains such as Motion Planning, Perception, Human-Robot Interaction, Manipulation, and Medical Robotics, allowing the course team to identify which topics sparked or sustained enthusiasm over time. Second, participants were asked how likely they were to pursue these areas in future coursework, research, or professional contexts, providing insights into whether the hands-on labs fostered stronger long-term commitment. Finally, students self-assessed their readiness for advanced robotics tasks, particularly their comfort with ROS, their familiarity with programming languages (such as Python and C++), their documentation processes, and their overall ability to apply theoretical concepts to practical challenges. To enable a clear comparison, survey items aligned closely with those used in 2022–2023, making it possible to evaluate the influence of the new labs on both mid-semester and end-of-semester attitudes.

To evaluate the effect of the newly introduced lab sequence, data from last year's course iterations (2023) were compared with feedback collected in 2024. In both years, students answered survey questions using verbal descriptors—such as "Extremely interesting," "Somewhat likely," or "Extremely comfortable"—which were subsequently converted into a 1–5 scale for analytical purposes. Three main categories emerged from this process: (1) interest in core robotics topics, (2) likelihood of pursuing these areas further, and (3) preparedness and comfort with essential robotics tools.

Furthermore, although no formal lab feedback forms were collected from teaching assistants, the instructor and teaching assistants held weekly meetings to discuss each lab's progress and emerging challenges. While these sessions were not documented in a rigorous manner, they offered informal perspectives on common student difficulties and possible areas for improvement. More systematically, qualitative insights were gathered through open-ended questions on the midterm and final feedback surveys. Students were invited to comment on the course structure, the newly implemented labs, and their overall experiences, thus adding context to the quantitative results and illuminating how the course modifications shaped their learning.

The analysis proceeded along two lines. Quantitatively, average scores for interest, likelihood of pursuing topics, preparedness, and comfort were calculated at the mid-term and final stages, then compared with equivalent metrics from the previous year. This approach highlighted any notable shifts that corresponded to the introduction of the lab sequence. Qualitatively, open-ended survey responses underwent a thematic review, focusing on recurring issues such as requests for additional hardware time, reflections on lab complexity, and opinions on how effectively course activities bridged theory with real-world applications. Considering both numerical trends and student commentary, this evaluation provides a holistic view of whether the lab sequence successfully addressed previously observed gaps in engagement and skill mastery.

Results

To evaluate the effect of the newly introduced lab sequence, data from last year's course iterations (2023) were compared with feedback collected in 2024. In both years, students answered survey questions using verbal descriptors—such as "Extremely interesting," "Somewhat likely," or "Extremely comfortable"—which were subsequently converted into a 1–5 scale for analytical purposes. Three main categories emerged from this process: (1) interest in core robotics topics, (2) likelihood of pursuing these areas further, and (3) preparedness and comfort with essential robotics tools.

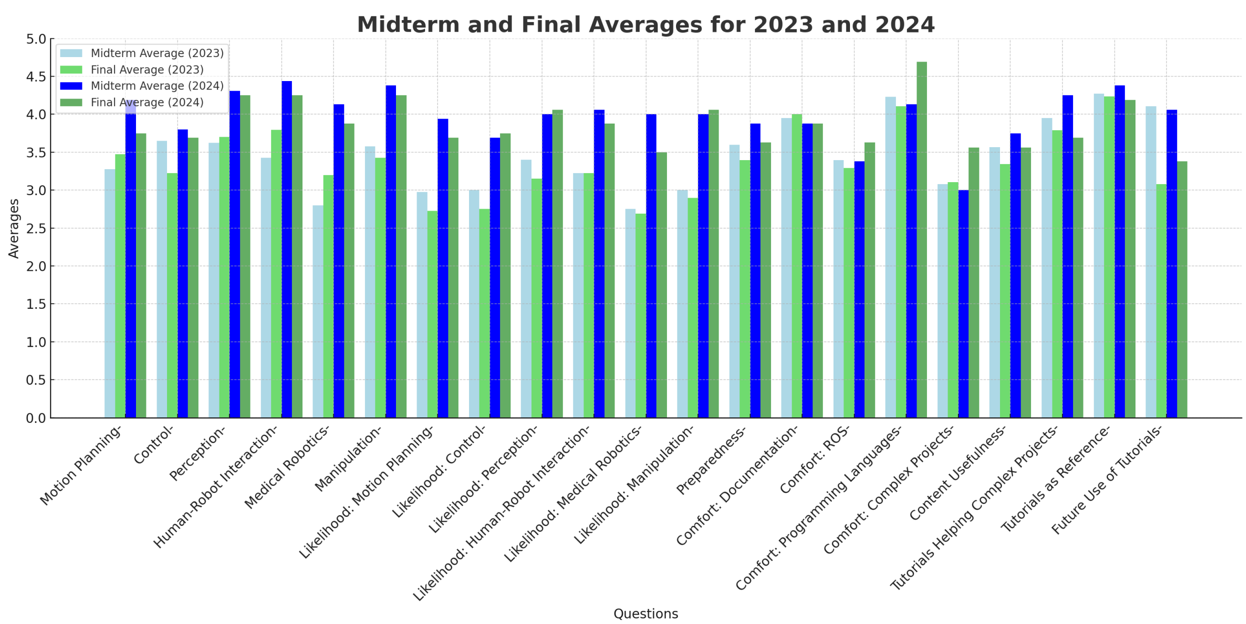

Figure 1: Comparison of Midterm and Final Mean Scores for 2023 and 2024 Across Various Metrics

Interest in Robotics Topics

Students reported their interest in several key robotics domains, including Motion Planning, Perception, Human-Robot Interaction, Manipulation, and Medical Robotics. In 2023, interest in

Motion Planning showed a modest increase over the semester (3.28 → 3.48), while in 2024 it started higher (4.19) but dropped slightly to 3.75 by the final survey. This pattern suggests that students' enthusiasm was initially piqued—likely by hands-on lab exercises—but later shifted to other areas offering more immediate, tangible projects.

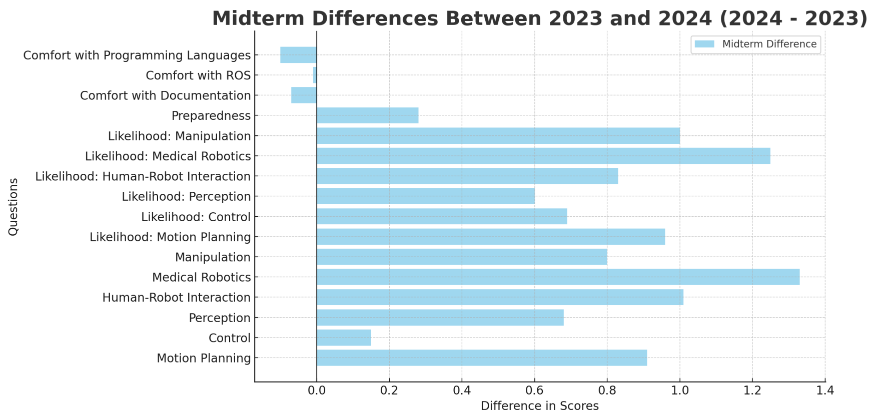

Figure 2: Mean Midterm Scores Comparison: 2023 vs. 2024

For Perception, scores in previous years rose only marginally (3.63 → 3.70). By contrast, 2024 data showed a substantial starting point (4.31) that remained relatively high at 4.25 by semester's end. This improvement appears tied to labs featuring TurtleBot 4 and LIDAR integration, which gave students practical exposure to sensor-based tasks rather than leaving them to learn abstractly.

In the case of Human-Robot Interaction, interest climbed from 3.43 to 3.79 in the earlier format, whereas in 2024 it stayed consistently higher (4.44 → 4.25). The new labs initially drove a strong uptick, though by the final survey, emphasis on topics like Perception and Manipulation slightly overshadowed Human-Robot Interaction in actual project work. Manipulation also benefited from structured practice: although it declined a bit in 2022–2023 (3.58 → 3.43), it held robustly in the new setup (4.38 → 4.25), reflecting positive engagement with the hands-on tasks from Labs 5 and 6.

Medical Robotics saw the most pronounced drop among all topics measured in 2024 (4.00 → 3.50). Students who initially found it compelling did not sustain that interest, implying a need for either dedicated lab content or specialized project pathways if the course seeks to maintain enthusiasm in this area over time.

Likelihood of Pursuing Robotics Topics

When asked how likely they were to continue exploring these domains, the pattern for Motion Planning followed a similar trajectory in both course formats, with likelihood declining from midterm to final. This decline could reflect the complexities inherent in bridging theoretical motion planning concepts with real-world implementation, as well as the shift of student attention to more immediately rewarding tasks in other areas.

By contrast, Perception likelihood showed distinct gains once hands-on sensor integration was introduced in 2024 (4.00 → 4.06), rather than the drop observed previously (3.40 → 3.15). Similarly, the likelihood of pursuing Human-Robot Interaction began higher in the revised course (4.06) than it had in the older iterations, though it saw a minor reduction to 3.88, possibly due to students gravitating toward practical challenges in Perception or Manipulation labs. Meanwhile, Medical Robotics slipped from 4.00 to 3.50 in 2024—paralleling the trend in interest levels and suggesting an untapped opportunity for more robust, hands-on medical robotics content.

Preparedness and Comfort

Students also rated their overall sense of preparedness and comfort with core tools and concepts. For preparedness, both the older and newer cohorts saw a dip from midterm to final; however, the 2024 group started at a noticeably higher level (3.88 vs. 3.60) and ended at 3.63, whereas the previous cohort ended at 3.39. This trajectory indicates that while the lab sequence conferred early benefits—helping learners feel more equipped by midterm—the complexity of later labs did challenge them, leading to a slight reduction in final self-assessments.

Comfort with documentation remained nearly unchanged under the new lab design (3.88 → 3.88), whereas a small improvement had been noted in previous years (3.95 → 4.00). This outcome hints that, despite their technical gains, students could still benefit from more systematic guidance on writing and referencing documentation. In contrast, ROS comfort showed a clearer upswing in 2024, moving from 3.38 to 3.63, whereas it had modestly declined (3.39 → 3.29) in the older format. The incremental, hands-on tasks across multiple labs evidently boosted students' ability and confidence in using ROS.

Finally, programming language proficiency displayed one of the largest positive shifts under the new system, climbing from 4.13 to 4.69, compared to a small decrease in previous years (4.23 → 4.11). Frequent, progressively challenging coding assignments embedded throughout the labs likely helped students build stronger competencies and tackle more sophisticated final projects, reinforcing the value of regular, purposeful practice. Overall, these findings underscore how the structured lab sequence influenced interest, likelihood of continued study, and technical confidence in robotics. While areas like Perception and Manipulation benefited greatly from the hands-on approach, topics like Medical Robotics and documentation practices emerged as opportunities for further curriculum refinement.

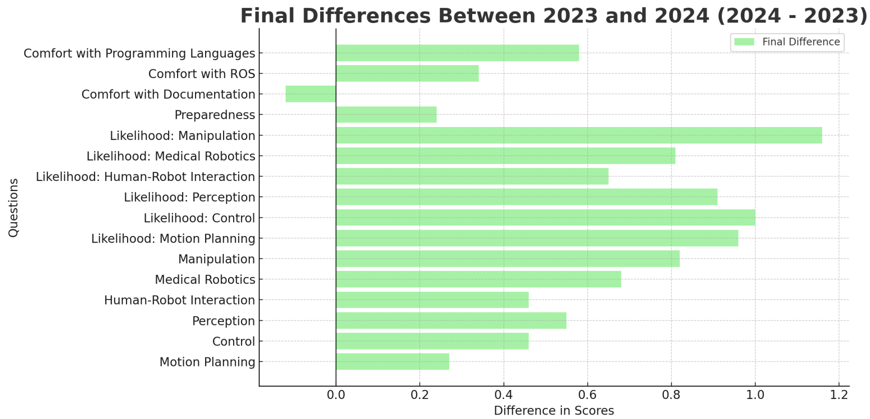

Figure 3: Mean Final Scores Comparison: 2023 vs. 2024

Discussion

The introduction of incremental, hands-on labs in 2024 significantly enhanced students' engagement with the course material. Previously, most interaction with robotics concepts remained largely theoretical, particularly for individuals not working directly with physical hardware. Under the revised format, learners advanced from basic simulations to more realistic setups, employing tools such as TurtleBot 4 and UR5e arms. This progression not only sparked enthusiasm but also underscored the real-world relevance of topics like Perception and Manipulation. By the midterm, the survey data indicated higher levels of ROS comfort and programming confidence than those seen in prior years, suggesting that early experiential assignments laid a solid groundwork for deeper learning.

Despite these strong beginnings, many students encountered a "complexity plateau" as they progressed to Labs 6–9. While Labs 1 through 5 offered structured introductions to Linux, Git, and ROS fundamentals, leading to manageable tasks in manipulation and path planning, subsequent projects required stacking multiple blocks and performing autonomous mapping, significantly heightened the challenges. This jump in difficulty led to modest dips in reported preparedness, reflecting the realities of tackling sophisticated robotics applications. However, such hurdles also reinforced resilience in problem solving, mirroring the way real-world robotics tasks often grow in scope and complexity over time.

Meanwhile, certain specialized areas like Medical Robotics and Motion Planning, which initially attracted high interest, saw reduced engagement by semester's end. Much of the course's emphasis rested on TurtleBot navigation and manipulation exercises, leaving less room for these more focused domains. Students would potentially benefit from additional application-specific labs or dedicated project tracks in these topics to maintain the initial momentum. Offering optional projects in medical robotics, for instance, might help sustain the early enthusiasm observed in the surveys.

Alignment with Observations

Although formal observational data were not systematically recorded, regular discussions between the instructor and TAs affirmed many of the survey-based findings. As students became more adept with foundational skills, they increasingly called for open-ended tasks that could accommodate their growing creativity. Such autonomy, introduced through supplementary assignments or more flexible lab structures, led some learners to customize simulation environments, experiment with unconventional sensor inputs, and explore unaddressed areas in manipulation and navigation.

Final projects in 2024 further illustrated this growth. In comparison to previous years, student groups demonstrated a markedly higher level of ambition and innovation. Master's students, for example, took advantage of the UR5e arm or a TurtleBot 3 in physical settings, while undergraduates pushed the boundaries of simulation with complex, previously unseen scenarios. A few teams even incorporated novel robot platforms beyond the official course curriculum, revealing both heightened confidence and a capacity for independent learning. Collectively, these outcomes validate the course's progressive lab model, highlighting students' readiness to tackle robotics challenges well beyond the classroom environment.

Student Written feedback

Student feedback on the redesigned course and its associated labs largely pointed to an improved overall experience, though areas for future enhancements also emerged. Early labs garnered positive reception, with participants noting that the manuals were generally clear and easy to follow. However, some students raised a "copy-paste" concern, stating that several early assignments felt overly prescriptive. They expressed a preference for more problem-based or exploratory tasks that would allow them to experiment freely and apply creativity rather than strictly following step-by-step instructions.

Regarding hardware usage, while simulations were considered valuable for learning core concepts, many students indicated a desire for earlier and more frequent exposure to physical robots. This feedback aligns with the course data suggesting that hands-on interaction promotes deeper engagement and confidence. TA support also received commendations, with students praising the teaching assistants' knowledge and responsiveness. Nonetheless, in periods of high demand—particularly right before lab deadlines—some learners found it challenging to receive timely help, hinting at a need for additional TA coverage or more structured consultation times.

Anecdotes from the final projects offered insight into how students synthesized the skills learned throughout the semester. One team developed a multi-step manipulation routine to track various pastries—such as cookies, donuts, and muffins—using computer vision, then used a UR5e arm to extrude icing onto them in precise patterns. This project showcased a sophisticated integration of object recognition, motion planning, and actuation. In another example, two teams leveraged TurtleBot 3 platforms to map the lab environment—a space characterized by frequent reconfiguration and dynamic obstacles—demonstrating the application of advanced ROS2 packages for navigation and SLAM (Simultaneous Localization and Mapping). These diverse and ambitious projects underscored the extent to which the redesigned labs equipped students with the confidence and technical breadth to tackle highly creative, real-world robotics challenges.

Future Work

Expanding hands-on interactions with physical robots represents a key area for improvement, particularly for undergraduate students who currently lack the opportunity to engage with hardware beyond demonstrations. Introducing at least one structured lab session that utilizes scaled-down or simplified robotic systems would enable all learners to experience the transition from simulation to real-world implementation. This approach could extend to new platforms like Crazyflie drones, thereby diversifying the learning experience and inspiring greater enthusiasm across varying skill levels.

Additionally, refining both the lab and homework structures would address students' desire for more exploratory tasks. While prescriptive labs are valuable for teaching fundamentals, optional challenge assignments could be formalized into "tracks" targeting areas such as advanced motion planning, UAV flight, or medical robotics applications. By shifting certain "copy-paste" labs to at-home assignments, in-person lab periods could focus more on higher-level problem-solving, collaborative activities, and guidance from teaching assistants. These adjustments would not only foster deeper engagement but also capitalize on the in-lab time for creativity and mentorship.

Another recommendation involves expanding documentation resources and wiki support. A mid-semester wiki has already proven effective for aggregating tutorials, command references, and troubleshooting notes; building on this foundation would establish a living repository of best practices and clarify common issues for novices. Encouraging student contributions—such as code samples or short guides—can further cultivate a shared knowledge base that evolves with the course.

To sustain early enthusiasm in areas like medical robotics, smaller-scale examples or mini-projects integrated into the introductory syllabus could highlight how robotics intersects with specialized domains such as surgical tool manipulation or medical imaging. Despite the existence of a separate medical robotics class, weaving lighter versions of these topics into the current curriculum may help maintain student interest.

Finally, enhancing TA support and capacity remains crucial. Although TAs received praise for their expertise, limited availability during peak times sometimes hindered timely assistance. Structured office hours, sign-up slots for individual guidance, or designated TAs specializing in particular "tracks" (e.g., UAV flight or manipulator control) could address these challenges. Consolidating FAQ lists and reference sheets could also ease the learning curve for novices encountering ROS or command-line tools for the first time. In sum, these recommendations—expanding physical robot access, refining lab structures, strengthening documentation and wiki resources, incorporating medical robotics content, and bolstering TA support—are all integral steps toward creating a more inclusive, comprehensive, and inspiring robotics education experience.

Conclusion

The shift in the introductory robotics course from providing only tutorials and homework exercises in previous years to introducing nine structured labs in 2024 significantly enhanced students' capacity to transition from theory to hands-on practice. While learners had previously encountered Linux, Git, and ROS through standalone materials, they often worked in isolation without guided lab support—leading to uneven skill development and a gap between theoretical understanding and real-world application. Under the new lab sequence, these same tools were presented incrementally and with purposeful scaffolding, allowing students to deepen their engagement and systematically build competencies.

Comparisons between the 2022–2023 and 2024 cohorts reveal meaningful gains in students' interest and confidence levels across key robotics domains, including Perception, Manipulation, and Motion Planning. Likewise, comfort with programming and ROS climbed notably, as lab assignments required iterative problem-solving and reinforced best practices rather than leaving students to navigate tutorials on their own. Feedback from both midterm and final surveys also pointed to areas for refinement, such as introducing hardware earlier in the semester for all students, offering more open-ended "challenge" assignments, and strengthening documentation practice.

The diverse and ambitious final projects—spanning tasks like advanced manipulation routines and mapping dynamic environments—illustrate how a structured, lab-centric approach can empower students to tackle real-world robotics challenges. Going forward, expanding TA support, providing supplemental wiki resources, and leveraging multiple hardware platforms (including newly added drones) will help the course continue evolving into a robust, student-centered learning environment. This case study underscores that methodical, progressively challenging labs, aligned with appropriate instructor guidance, can play a critical role in bridging the gap between theoretical exposure and the applied problem-solving skills essential for success in robotics.

Lessons Learned

- **Balance Between Prescriptive and Open-Ended Tasks**
  - *Issue:* Early labs with heavy guidance helped novices but limited creativity.
  - *Lesson:* Provide step-by-step structure for fundamental concepts, then transition to more exploratory tasks once students gain confidence.
- **Early, Incremental Scaffolding Is Crucial**
  - *Issue:* Students previously struggled to connect abstract theory to hands-on work without guided steps.
  - *Lesson:* Introducing Linux, Git, and ROS incrementally in the first few labs builds a foundation that supports more complex tasks later in the course.
- **Authentic Challenges Foster Deep Engagement**

- *Issue:* Straightforward exercises did not fully prepare students for real-world complexities.
- *Lesson:* Tasks such as multi-block manipulation or maze mapping, while more difficult, drive problem-solving resilience and mirror industry scenarios.

- **Hardware Access Drives Confidence and Motivation**
  - *Issue:* Undergraduates often had limited or delayed exposure to physical robots.
  - *Lesson:* Earlier and broader integration of hardware—even if scaled-down—boosts student engagement and better aligns theory with tangible practice.
- **Documentation and Self-Guidance Require Ongoing Support**
  - *Issue:* Comfort with documentation did not notably improve despite lab-based learning.
  - *Lesson:* Encourage writing logs, code annotations, and wiki contributions to reinforce best practices and improve overall technical communication skills.
- **Adaptive TA Support Can Mitigate Bottlenecks**
  - *Issue:* High demand near deadlines caused delays in assistance.
  - *Lesson:* Structured help hours, online Q&A sessions, or TA "track" specialization reduce waiting times and help students tackle complex labs more effectively.
- **Varied Tracks Maintain Broad Interest**
  - *Issue:* Topics like Medical Robotics and advanced Motion Planning lost traction once the labs shifted focus.
  - *Lesson:* Providing optional, track-based assignments or "challenge homeworks" keeps specialized areas in play and sustains early enthusiasm.
- **Progressive Complexity Encourages Realistic Skill Development**
  - *Issue:* Without a clear progression, students in previous years jumped into tasks that felt too advanced.
  - *Lesson:* A structured sequence—from simple publisher-subscriber scripts to advanced path planning—helps learners see their growth and apply skills more confidently.
- **Opportunities for Innovation Expand Project Ambition**
  - *Issue:* Rigid tutorials limited how far students extended final projects.
  - *Lesson:* Leaving space for creativity and student-initiated research (e.g., new robot platforms) encourages higher-level learning and showcases a capacity for independent exploration.

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