Teaching Requirements Engineering to Robotics Students Through Reverse Engineering: An Experience Report

Jeshwitha Jesus Raja[1], Shaza Elbishbishy[1], Jennifer Brings[2] and Marian Daun[1]

[1]*Technical University of Applied Sciences Würzburg-Schweinfurt, Schweinfurt, Germany*
[2]*Bingen Technical University of Applied Sciences, Bingen, Germany*

Abstract

Robotics students are primarily trained through ex-cathedra teaching methods that emphasize mathematical and technical instruction. As a result, soft skills—such as requirements elicitation, translating complex technical concepts, and stakeholder communication—are often underdeveloped. However, these skills are fundamental to Requirements Engineering (RE), which plays a crucial role in designing and developing robotic systems. Despite its importance, RE is often overlooked in robotics education due to its perceived detachment from technical aspects, making it difficult for students to grasp. To address this challenge, we introduce reverse engineering activities as an approach to teaching RE to robotics students. By analyzing existing systems, students develop an applied understanding of RE principles, bridging the gap between technical knowledge and requirements. This paper presents our experiences with this approach, discussing its feasibility and effectiveness in enhancing students' comprehension and engagement with RE.

Keywords

Teaching, Requirements Engineering, Robotics, Reverse Engineering.

1. Introduction

Requirements specification specifies various types of requirements during system development, such as user requirements, functional requirements, performance requirements, design requirements, and so on [1]. System requirements are particularly useful for the development of robotic systems. For software-intensive robotic systems, the requirements elicited can be translated into control-oriented specifications, which provide detailed information about the expected behaviors, constraints, and system interactions [2]. These specifications form the foundation for designing, testing, and validating the control algorithms and architectures that govern a robot's operations. Consequently, it is important to include RE as part of the course module in robotics engineering.

Robotics degree programs, which are primarily composed of technical subjects and often emphasize a "build first, test later" mindset, may not adequately prepare students for abstract thinking and effective collaboration in the design phases of robot development [3]. This makes it difficult for robotics students to grasp the concepts of RE. Therefore, by integrating RE into the curriculum, students can develop the skills needed to approach robot design systematically and the soft skills needed to deal with end users, managements, and other stakeholders, ensuring a better balance between theoretical planning and practical implementation.

Reverse engineering is an approach to learning that involves analyzing an existing system to identify, interpret, and represent its underlying requirements, structure, and functionality [4]. In the context of robotics education, this approach allows students to deconstruct a pre-existing robotic system, gaining insights into its design, operational logic, and the rationale behind specific engineering choices. By

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jeshwitha.jesusraja@study.thws.de (J. Jesus Raja); shaza.elbishbishy@study.thws.de (S. Elbishbishy); j.brings@th-bingen.de (J. Brings); marian.daun@thws.de (M. Daun)
0009-0008-7886-7081 (J. Jesus Raja); 0009-0002-0975-272X (S. Elbishbishy); 0000-0002-2918-5008 (J. Brings); 0000-0002-9156-9731 (M. Daun)

engaging in this process, students develop not only a deeper technical understanding but also essential soft skills such as critical thinking, problem-solving, and communication.

Furthermore, reverse engineering often involves collaborative teamwork, where students must work together to analyze the system, discuss findings, and transform their interpretations into well-structured requirements. This fosters effective communication, negotiation, and coordination—key competencies in RE. Through hands-on experience, students refine their ability to translate technical insights into requirements specifications.

By combining technical analysis with collaborative learning, reverse engineering serves as an effective method for bridging the gap between robotics engineering and formal RE practices. In this paper, we observe the feasibility of this approach by applying reverse engineering in a RE course for robotics students.

The paper is structured as follows: Section 2 discusses research related to the education of RE, with a specific focus on robotics engineering. It also explores the current tools and techniques used in teaching this subject. Section 3 describes the RE course setup within the robotics program and explains the implementation of the reverse engineering approach for instructing students. Section 4 describes the application of this approach within the existing robotics degree program. Next, Section 5 discusses our experience with the application of the proposed approach. Finally, Section 6 concludes the paper by summarizing the findings and suggesting directions for future work.

2. Related Work

RE is a critical discipline in software development, focusing on defining and managing system prerequisites [5]. The field of RE education has evolved significantly over the years, with notable advancements in recent research. It plays a crucial role in preparing future engineers for high-quality software development and project success [6]. This educational field covers a broad range of topics, including traditional analysis, modeling skills, interviewing techniques, and writing skills for requirements specification [7]. However, RE education approaches typically target computer science students.

In robotics, RE education is a multifaceted field addressing various aspects of software and system development. While all RE phases are covered through different methods and modeling styles, there is a greater emphasis on elicitation and specification compared to validation, analysis, negotiation, and management [8]. Moreover, educational robotics requires tailored solutions to meet the unique needs of students and educators, which differ from those in commercial applications [9].

RE education faces challenges in preparing students for real-world scenarios, especially with limited academic resources. A recent survey highlights the importance of experiential learning through projects, collaboration, and realistic stakeholder involvement [10]. Role-playing has proven to be an effective tool for engaging students with real-world RE challenges [7, 11], while systematic processes for elicitation and specification have successfully achieved learning outcomes [12]. Additionally, involving stakeholders in RE education emphasizes elicitation techniques and enhances student skills such as motivation and communication [6].

RE education focuses on three core areas: analysis and modeling skills, interviewing and group work skills for requirements elicitation, and writing skills for specifying requirements [7]. These approaches help students develop both theoretical knowledge and essential soft skills necessary for effective RE practice. The use of online support tools further enhances the learning experience [11].

While these findings underscore the importance of adopting a comprehensive and practical approach to RE education, the existing approach lacks a focus on students with technical backgrounds, and the education of RE needs to be adapted to better serve these students.

3. Setting and Course Design

The RE course is a core elective in the sixth semester of the robotics degree program. It introduces students to various RE activities and techniques, including requirement gathering, negotiation, validation, and specification. Students learn textual, model-based, and combined requirement representations. By the end of the course, they develop the skills needed to address challenges in defining requirements for embedded systems, with a focus on robotics. They also learn to define goals and scenarios to assess requirement satisfiability, identify inconsistencies and defects, and ensure alignment with stakeholder intentions. This study investigates the feasibility of a reverse engineering approach in supporting robotics students' learning and achievement in the RE domain.

During the course, students work in teams to complete three interconnected assignments over the semester. The first assignment requires them to produce a textual representation of requirements using natural language, allowing flexibility in template selection. The second assignment involves creating goal-based representations, where Goal-Oriented Requirements Language (GRL) is used to develop goal models. In the final assignment, students generate sequence-based representations using Message Sequence Chart (MSC).

To implement this approach, students are introduced to a pre-existing system, with its requirements verbally explained by lab engineers working with the system. A meeting follows, where the necessary workspace setup for the system was described to the students. Students then engage in a Q&A session to clarify system details. This shifts the students' understanding of system implementation to specifying system requirements for the system implementation. The abstract nature of the use case fosters interpretation, encouraging students to explore diverse perspectives and solutions.

The activity structure emphasizes iterative learning. Teams follow monthly deadlines, presenting their progress after each phase. These presentations include feedback sessions facilitated by the professor, along with peer evaluations. This iterative process helps students refine their work while exposing them to alternative viewpoints and approaches.

4. Application

As a case application, a Human-Robot Interaction (HRI) system designed for collaborative assembly processes was chosen. In this setup, a human and a collaborative robot (cobot) work together within a shared workspace to assemble components without physical barriers separating them. Unlike traditional robotic systems, collaborative assembly requires real-time coordination, as the human and robot must dynamically adapt to each other's actions while ensuring safety. This demands precise task planning and robust safety protocols to mitigate risks associated with close HRI. Consequently, well-defined RE is crucial for ensuring the system's effectiveness, safety, and overall success. Figure 1 illustrates the HRI-based setup, which includes a cobot, a human user, assembly components, assembly tools, and a monitoring system.

Students were divided into two teams. After gathering the necessary information, the teams began with the natural language requirements specification. This initial task focused on documenting the functional requirements, quality requirements, and constraints of the HRI system.

Once the first task was completed and submitted, the teams proceeded to the second task: the goal-based requirements specification. The teams identified goals, soft goals, tasks, and resources for the collaborative assembly process setup. The resulting models demonstrated how the goals were composed of tasks, how soft goals contributed to the achievement of goals, and how resources and tasks were interconnected.

After completing the goal-based specification, the teams proceeded to the third task: the sequence-based requirements specification. This task illustrated how interactions occur within the collaborative workspace and was reverse-engineered from the system once again. Ensuring consistency across all three artifacts was a key consideration. Students also learned that while different perspectives can be used to express various aspects of a system, overlaps between these perspectives exist and must be maintained consistently.

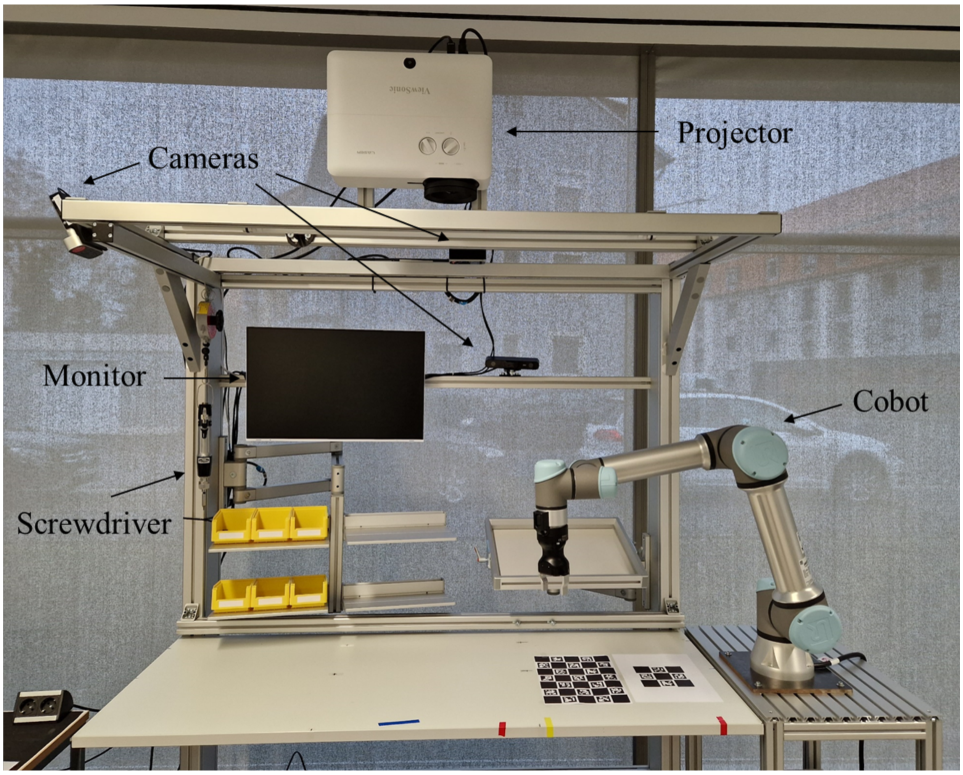

Figure 1: Assembling Workspace

5. Discussion

Through the experience of implementing reverse engineering, we wanted to understand the following:

RQ1: How does the proposed reverse engineering approach affect robotics students' understanding and application of RE principles?

RQ2: How feasible is the reverse engineering approach as a teaching method for enhancing robotics students' understanding of RE?

5.1. RQ1: How does the proposed reverse engineering approach affect robotics students' understanding and application of RE principles?

Robotics students face several challenges in understanding and applying RE concepts, primarily due to the abstract nature of these principles and the technical focus of their education. Concepts like stakeholder analysis and requirement specifications differ significantly from the hands-on tasks students are accustomed to, such as programming and system design. Additionally, topics like GRL and MSC are often unfamiliar, as conceptual modeling is only minimally addressed in most robotics programs. The collaborative and communication skills required for effective RE are also underdeveloped, as robotics education often emphasizes individual technical tasks.

The technical nature of robotics exacerbates these challenges. Students tend to focus on creating functional systems, prioritizing implementation over the systematic documentation of requirements. The technical mindset of aiming for one "correct" solution makes it difficult for students to appreciate diverse perspectives, further complicating the breakdown of problems into manageable requirements. Moreover, the time pressure associated with developing prototypes often leaves little opportunity to adopt systematic RE practices.

We believe that the reverse engineering approach helped address these challenges, as its practical nature seemed to support students in developing their soft skills and improving their understanding of the syntax and semantics of GRL and MSC. This approach appeared particularly beneficial for learning conceptual models, a topic that is rarely emphasized in robotics programs.

Participating in meetings gave students real-world context for requirements specifications, highlighting the importance of documenting such information thoroughly. Receiving feedback throughout the semester and examining problems from multiple perspectives, including other teams' specifications, helped students deepen their understanding of RE principles and apply this knowledge to their own work. Team-based activities further enhanced their collaborative skills, leading to improved learning outcomes.

By starting with an existing robotic system, students were able to bridge abstract RE concepts with tangible examples, making these concepts easier to understand. Team-based activities and stakeholder simulations improve collaboration and communication, while the hands-on reverse engineering process helps students learn how to structure and document requirements effectively. This approach bridges the gap between technical and conceptual knowledge, enabling students to overcome the challenges of integrating RE into robotics education.

These understandings through this approach reflected on the exams, where students were able to show their understanding of creating conceptual models and drafting requirements.

5.2. RQ2: How feasible is the reverse engineering approach as a teaching method for enhancing robotics students' understanding of RE?

The feasibility of implementing a reverse engineering approach in a RE curriculum depends on several key factors. Firstly, integrating reverse engineering into the course requires minimal adjustments to the existing structure, as it aligns well with the theoretical concepts of what is being taught during class. The flexibility of reverse engineering assignments allows them to be adapted to varying levels of difficulty and complexity, making them suitable for a wide range of students.

One challenge lies in organizing and facilitating the necessary meetings, which are crucial for simulating real-world scenarios. Although this requires coordination and time management, it is manageable within the course design, especially since the course is conducted in-person and these meetings can take place during class hours. Furthermore, the collaborative nature of the activity demands that instructors provide adequate guidance and ensure balanced team participation. This is where the iterative, team-based approach of reverse engineering—supported by continuous feedback and refinement—proves beneficial.

Overall, the reverse engineering approach seemed feasible for teaching RE to robotics students, as long as it is seamlessly integrated with the course's theoretical content. The method's adaptability to course structures, combined with its practical and collaborative nature, makes it an implementable teaching strategy.

6. Conclusion and Future Work

RE is fundamental to designing and developing robotic systems, but its disconnect from the technical aspects of robotics often leads to it being overlooked, making it difficult for robotics students to fully grasp its importance and application. In this paper, we proposed a reverse engineering approach specifically tailored for students with technical backgrounds, such as engineering students.

The proposed approach addresses these challenges by offering a practical, hands-on framework for teaching RE. This method enhances students' understanding of RE through team-based activities and real-world simulations, fostering critical thinking, creativity, and collaboration. By actively engaging with elicitation, goal modeling, and scenario-based specifications, students gain firsthand experience in structuring and documenting requirements.

Our experience suggest that the reverse engineering approach improves students' comprehension and application of RE principles by linking theoretical concepts to tangible robotic systems. The feasibility of this method is reinforced by its adaptability to project-based learning environments and its alignment with the iterative, feedback-driven nature of engineering education. Additionally, the structured team-based approach ensures balanced participation and helps students develop essential soft skills, such as communication and problem-solving, which are often underemphasized in robotics curricula.

By bridging the gap between abstract RE principles and their practical relevance, this approach equips students with the skills to manage complex engineering projects and emphasizes the critical role of systematic documentation in robotics. Integrating this approach into robotics education can improve how students learn and apply RE concepts, making it a viable and effective strategy for addressing the challenges associated with teaching RE in technical disciplines.

As is common in case study-based evaluations, the generalizability of the reverse engineering approach cannot be assumed without testing it with a larger participant group. Since our findings are based on a single group of students and one case example, we plan to repeat this study with additional groups and diverse case applications to conduct a more thorough investigation. To assess the effectiveness of this approach, we want to gather feedback through surveys and qualitative insights from students. Additionally, we aim to identify and account for external factors that may influence the success of this approach, ensuring a more comprehensive and validated evaluation.

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