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RISE: A project-based learning framework for student-driven exoskeleton development

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Abstract: This paper presents RISE, a transdisciplinary project-based teaching framework in which students iteratively develop a robotic exoskeleton for individuals with spinal cord injury. The course integrates agile SCRUM processes, competence-oriented alignment and user-centered design within an authentic engineering context. Multi-semester evaluations show consistently high student ratings and strong motivation despite substantial workload. External benchmarking is provided through participation in the CYBATHLON 2024 finals, where the student-developed system achieved fourth place overall.

I. Introduction

Engineering education increasingly shifts from knowledge transmission towards competence-oriented, application-driven learning formats. Inverted and project-based approaches have demonstrated positive effects on learning outcomes and student engagement in STEM disciplines [1], [2]. However, complex domains such as medical robotics require learning environments addressing system integration, interdisciplinary interfaces and responsibility for real-world consequences. RISE (Research and Innovation in Student Exoskeleton Development) addresses this gap by embedding students in an authentic, safety-critical development process with system-level responsibility, involving the iterative design, implementation and evaluation of a robotic exoskeleton for people with spinal cord injury. The teaching format is comparable to competition-based engineering initiatives such as Formula Student, which foster deep learning and professional identity formation [3]. External benchmarking in performance-driven evaluation settings with strict technical and safety requirements further aligns educational objectives with professional engineering practice.

II. Educational Framework

The educational concept of RISE combines project-based learning, agile development processes and competence-oriented alignment to address the challenges of complex, interdisciplinary engineering education.

II.I. Transdisciplinary Project-Based Learning

RISE is structured as an integrated project-based learning (PBL) environment spanning up to four modules and optional thesis projects. Students from medical engineering, mechanical engineering, electrical engineering, computer science, human factors and social sciences work in integrated teams covering mechanics, electronics, control software, human–machine interfaces and biomechanics toward a shared system-level goal. Prior research shows that authentic PBL environments foster higher-order competencies such as problem-solving and collaboration [3], [4].

II.II. Agile Development using SCRUM

To manage high system complexity and interface density, RISE employs SCRUM-inspired agile processes. Iterative development cycles, sprint reviews and retrospectives structure the learning process and enable continuous feedback and coordination. Empirical studies indicate that agile frameworks such as SCRUM improve team coordination, transparency and student engagement in project-based engineering education [5]. In RISE, agile methods are applied directly to real hardware and software development tasks rather than taught abstractly.

II.III. Competence-Oriented Alignment

To ensure coherence between learning goals, activities and outcomes, RISE follows a competence-oriented alignment framework. Students progressively assume responsibility for subsystems ranging from detailed component design to system-level integration, interface coordination and scientific dissemination. Such alignment is considered essential for sustainable learning outcomes and professional readiness [6].

III. Evaluation Methods

The teaching format has been implemented continuously since the winter semester 2022/23 and evaluated over multiple semesters using standardized course evaluations (evasys). Each iteration involves approximately 25–45 participating students. Evaluation data include quantitative Likert-scale items and qualitative open-text responses; due to voluntary participation, sample sizes range from $n = 11$ to $n = 21$. The evaluation conducted in the winter semester 2024/25 was excluded due to insufficient participation. Such instruments are widely used as indicators of perceived learning quality and instructional effectiveness [7].

IV. Results and Discussion

This section summarizes evaluation results and relates them to the observed technical outcomes of the RISE project.

IV.I. Evaluation Results

Across multiple semesters, course ratings remained consistently high, with mean scores between 1.4 and 1.8 on a 1–5 scale (1 = very good). Students reported particularly strong agreement with items related to comprehensibility, engagement and instructional support. Compared to faculty-wide reference values, RISE achieved equal or higher scores in most categories, especially regarding active student involvement and perceived teaching quality. A notable result is the high reported workload, with a substantial proportion of students indicating weekly efforts exceeding the nominal credit-point allocation. This aligns with findings from authentic project-based learning environments linking effort to higher perceived ownership and intrinsic motivation [4], [7].

IV.II. Technical Outcomes and Benchmarking

Beyond educational outcomes, RISE produced measurable technical results. Over multiple semesters, students developed, integrated and validated a functional lower-limb exoskeleton system, including mechanical structures, actuation, control software and user interfaces. The system successfully qualified for participation in the CYBATHLON 2024, which requires compliance with defined safety, robustness and usability criteria. During the competition, the RISE team reached the finals and achieved fourth place overall, providing external benchmarking of both the technical maturity of the system and the effectiveness of the underlying development process. Achieving this required addressing technical and organizational challenges including safety-oriented system architecture, trajectory development under limited testing time, system-level stability considerations, procurement constraints and reliable modular integration across subsystems. From an educational perspective, the competition context functions as a high-fidelity test environment in which system integration and reliability are evaluated under real-world constraints [3].

IV.III. Interpretation and Limitations

The evaluation indicates that RISE fosters technical, scientific and transversal competencies, while also revealing structural and procedural limitations. Not all student-developed concepts were implemented, as some approaches were deliberately discarded due to excessive complexity, unfavorable cost–benefit ratios or insufficient robustness for a safety-critical system. Furthermore, the substantial onboarding effort required for new participants leads to strongly varying self-defined timelines across teams, increasing the effort required for interface coordination and integration. Across multiple cohorts, recurring process-related barriers and facilitators became apparent. A central challenge was heterogeneous individual commitment within large interdisciplinary teams, occasionally leading to asynchronous subsystem progress. Key facilitators included tutor-guided SCRUM retrospectives enabling early identification of emerging conflicts and stabilization of group dynamics, as well as continuity through core team members and structured sprint reviews supporting interface clarification and prioritization. Limitations further include small cohort sizes and reliance on self-reported data. Future evaluations should therefore combine course evaluations with structured competence-oriented assessment rubrics already implemented within the modules [7]. Compared to established competition-based formats such as Formula Student, RISE is positioned as a complementary approach with strong curricular embedding and a safety-critical medical robotics context. Direct comparative evidence between such formats is currently limited and remains an open research question.

V. Conclusion

RISE demonstrates that a transdisciplinary, iterative and competence-oriented project-based format can be successfully implemented in medical engineering education. By engaging students in authentic development processes and real responsibility, the course achieves high motivation and robust perceived learning outcomes. Participation in the CYBATHLON 2024 finals and the achieved fourth place provide external benchmarking under real-world constraints. The framework is transferable to other complex, safety-critical engineering domains requiring tight hardware–software–human integration.

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