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EDUCATING FUTURE ROBOTICS ENGINEERS IN MULTIDISCIPLINARY APPROACHES IN ROBOT SOFTWARE DESIGN

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ABSTRACT

In 2020, a new two-year MSc programme in robotics was launched. Unlike most existing robotics programmes, which approach robotics from a specific discipline, this programme aims to train multi-deployable robot generalists using a cognitive approach (no hardware creation). The field of robotics is multidisciplinary by nature and educating students on how to approach projects with a multidisciplinary mindset is at the forefront of the programme. Hence, at the end of the first year, students are thrust into experiencing the true multi-disciplinarity of the robotics field in a synthesizing, multidisciplinary project-based course. In this 5 EC course, students work together in groups of 5 on an industry-based assignment making a translation of societal issues from different perspectives (human, sustainability, safety, ethics,

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economic, etc.) into intelligent robot solutions. Each team develops and tests a complete, integrated software package for a complex robot system in a simulated environment and implements it in a real robot at the end of the course. Various robots are used, each related to a different case study which is taken on by multiple teams. Students are supported in their project with workshops and minilectures on transferable skills, systems engineering and the Robot Operating System (ROS). This paper describes the development, implementation, and results of the course over its first three years of running. It will present lessons learned from the perspectives of all parties involved: lecturers, technical staff, industry, and students as well as future plans and recommendations for others looking at creating similar courses.

1 INTRODUCTION

The field of robotics, like other discipline-focused fields such as aerospace engineering and maritime architecture, is multi-disciplinary in nature. This is why in 2020 a new multi-disciplinary 2-year MSc degree in Robotics was set up at Delft University of Technology in the Netherlands. The MSc Robotics was developed together with students and industry, to ensure the relevance of this programme. It was first run in the academic year 2020-2021. Its focus is on educating future robot software engineers, who are comfortable in a variety of mechanical engineering and computer science disciplines including machine perception, artificial intelligence, robot planning and control, human-machine systems, and ethics. The robotics engineer is trained to be creative and to find solutions from different perspectives. As such, it is crucial for robotics engineers to receive education not only in a diverse array of purely technical disciplines but also in human-robot interaction as well as societal and ethical aspects.

The approach to training these robotics engineers is to guide them through several mandatory courses which are connected to the previously mentioned disciplines. In addition, a course called Vision and Reflection runs in the first 2 quarters of the first year, integrated into the other courses. To achieve the aim of becoming a Reflective Engineer (Hermsen et al 2022), reflection forms a key part of the programme. In this course, students discuss their experiences and future plans in terms of electives and skills development under the supervision of both a PhD candidate and an older student. More details on the entire MSc Robotics programme can be found in Saunders-Smits et al. (2023).

The RO47007 Multidisciplinary project is the last mandatory course in the first year of this new Master's programme. The aim of the project is to let the students work on a problem currently relevant to the robotics industry, while they practise and combine the knowledge they have found in the previous courses. They receive aid and feedback about how to run such a project in terms of communication and project management. This 5 EC course forms the synthesizing capstone project at the end of the first year before the students transition to the second year in engage in individual and diverse group work, using provided tools and methods while devising novel theories or design techniques to address intricate mechanical engineering challenges. In this paper, we will detail the course setup and the didactical concepts behind the course design, share our initial experiences, and report on a small study of student experiences in this year's run of the course.

2 COURSE DESIGN

2.1 Learning Objectives

The learning objectives for this course are divided into two domains: Knowledge, Insight, Judgment and Skills, and Transferable and Interpersonal skills. In the Knowledge, Insight, and Judgement & Skills domain, students should, by the end of the course, be able to:

- Define a problem definition and its corresponding requirements.
- Design relevant (robot) solutions in the field of robotics by integrating knowledge on opportunities, trends, and societal aspects.
- Design relevant (robot) solutions in the field of robotics by integrating knowledge on opportunities, trends, and societal aspects.
- Use functional architecture for planning and communicating robot software.
- Communicate the multidisciplinary robot solution in a clear way, both orally, in writing, and in code documentation.

In the Transferable and Interpersonal skills domain, students should, by the end of the course, be able to:

- Formulate and adjust learning goals on personal development
- Reflect on one's own competencies (e.g., Teamwork, Leadership, Entrepreneurial thinking, Strategic multidisciplinary problem solving) and development in these and determine where personal learning goals and interests lie;
- Show to use feedback to improve one's own performance or performance of others;
- Apply structured multidisciplinary software project management, with the use of different team roles and responsibilities

2.2 Course Set Up

In this 8-week course, students work in groups of 4-5, on an industry-based assignment making a translation of societal issues from different perspectives (human, sustainability, safety, ethics, economics, etc.) into intelligent robot solutions. Each team develops and tests a complete, integrated software package for a complex robot system in a simulated environment and tests this using a real robot at the end of the course. Since the second edition of the course, 4 robotics companies, research institutes or innovation centres supply students with a relevant challenge they face in their own robot development which they would like the students to provide solutions for. Each group of students consists of 5 so-called specialists, who are responsible for a specific part of the software design and implementation. The specializations used are *human-robot interaction, navigation, planning, perception,* and *motion control,* and relate to the different disciplines within robotics. In addition, students are also asked to choose other additional project management-based roles and their natural roles (such as team leader, etc.). They are asked to reflect on these roles as part of the continuous reflection within the course as a natural follow-up on the Vision and Reflection course. To mimic the project management styles used in the robotics industry the course planning is divided into 4 sprints to allow students to experience an Agile working approach. At the end of each sprint, a version of a living report should be handed in. Students receive feedback shortly after.

Students are supported in their project with workshops and minilectures on transferable skills, project management, systems engineering, and a refresher of the Robot Operating System (ROS) in which they were previously trained. These take place in the first 5 weeks of the project and are offered on a deliberate just-in-time basis. The client interaction in the course starts off with a company visit on the second day of the project, in week 4 students present their initial proposed design to their client for feedback and present their final design at the end of week 8. During this final presentation, students present a demonstration video of the robot executing their solution to the client's problem.

2.3 Robot design approach in the course

The Robotics master programme is very much focused on cognitive robotics and not on designing physical robots. Therefore, this project has been developed along this philosophy, in line with what most students will incur in industry once they graduate. They are expected to work with the robots and manipulators the company uses. All student groups work with simulations of a robot using ROS until they can test their software on the real-life version of their robot in weeks 5-7 of the course. In the 2022-2023 edition of the course, 4 different robots are used that are all available to students in-house: A Clearpath Robotics Boxer with a Panda arm to be deployed in supermarkets, a Boston Dynamics Spot (including arm) to look at the feasibility to employ it in object retrieval, a Clearpath Robotics Ridgeback with a Doosan arm to assist in part sorting and NDT scanning within airline operations, and a MIRTE robot to assist with barn safety for farmers working in cattle forms. Students are provided with Gazebo simulations of a simple environment and the representation of their robot through GitLab groups. They must create their own ROS nodes on top of the existing packages they have either received with the simulation or added them-selves. They use the same GitLab groups for version control and to store their documentation.

2.4 Didactic Approach

The MSc Robotics, which this course is part of, was established using the vision of Biesta (2021). He proposes an educational framework based on three key com-ponents - qualification, subjectivation, and socialization. In this project, students show qualification and further develop themselves in the subjectivation and socia-lization components. For the project, a Problem- Based learning approach has been chosen. As this is a Master's level course and students are assumed to have been sufficiently exposed to project-based education in their bachelor's, the most mature format within this segment as detailed by de Graaf and Kolmos (2003) has chosen, that of the Problem Project. This type of project is characterized by students being given a problem as a starting point (in our case by their industry client) which determines the choice of disciplines and methods to be used. The staff's role is to ensure the problem fits within the course's wider frame and to facilitate students with additional knowledge and skills training on a need-by-need basis.

This also means limited time is formally scheduled. The 8-week course has a work-load of 140 hours per student (15-20h per week) of which only 50 are formally scheduled, with less than half of that 50 hours with formal activities. Students are expected to independently plan the project as a group within the framework and milestones given. As the course started under COVID-19 restrictions, many of the workshops and instructions lectures were offered in a blended format. As this seemed to fit the need for independence within the project, this concept of offering as much of the supporting knowledge as online knowledge clips has been kept. Only the (inter)active workshops and assistance with robot and ROS instruction were introduced as face-to-face moments of knowledge transfer.

2.5 Reflection and Transferable skills

To address the Transferable and Interpersonal Skills learning objectives, students work on a personal development reflection assignment during the course as a natural follow-on from the Vision and Reflection course, starting from day 1. In addition to their technical expertise role, students are asked to investigate and reflect on what their natural project team role is. They are also asked to reflect on their strength and weaknesses and pick roles to fulfill within the team during the project. To ensure every student gets a chance to develop and experiment with team roles, teams are encouraged to rotate roles per sprint. To help them reflect and to learn to give and receive feedback students all follow a workshop on Peer feedback and cultural differences, offered by an external party. There is a deliberate focus on cultural differences given that a third of our students do not have a Dutch educational background. To allow them to practice giving feedback, use is made of peer evaluations, a form of peer assessment aimed at qualitative feedback on performance within teams (van Helden et al 2023). Students are asked to complete two peer evaluations during the project and to reflect on how they dealt with the feedback they received as part of their personal reflection chapter at the end of the project, for which they receive an individual grade. To assist in project management skills, students are introduced to the basics of project management including Agile in a workshop, where groups work together in developing a Work Breakdown Structure and a Gantt chart as living documents to be used throughout the project.

2.6 Course Experience and Fine Tuning to date

After the first editions of the course, student feedback was gathered through an evaluation panel discussion with four students. The students recognized the value of gaining experience working with real-world robots and transferring from simulation to the real world, which they found relevant to their academic and industry aspirations.

The students also suggested that the course name appeared to reflect that they would be collaborating with students from other faculties, beyond robotics alone, which will result in a name change in the future. Students also recommended improving the clarity and usefulness of the human-robot interaction specialist role. As a result, all assignments now involve the presence of a human in the testing space to enhance this role. An experiment using Scrum as a project management tool was carried out in edition 2 which did not work well for students and staff and has since been replaced by Agile. The educational format of a course, which has a defined end, does not fit within the Scrum philosophy of a continuous cycle of software development. Also, the reporting was adapted to fit an agile way of working, aiming to reduce over-reporting. Students also commented they felt the workload exceeded the 5EC given for the course (140h). The course staff is unsure whether students spend more than 140 hours, or if they underestimated what spending 140 hours in 8 weeks involved. To inform students better about the expected workload, a breakdown of expected hours per activity has been added to the introduction for 2022-2023 and the workload is a key focus in our study.

Initially, no industry clients were involved. The students suggested involving real companies to increase the relevance of client meetings and project urgency, an opinion that was shared by the staff. From the second run onward, four companies participated as clients, which was experienced as positive by staff, students, and clients alike, although a critical selection of the type of client is needed. Hence a set of criteria and standards for industry assignments in the course were developed. Other practical problems encountered by staff were the in-house availability of robots, dedicated robot-trained staff, as well as lecturers in preparing, facilitating, and grading the course, whilst still fine-tuning the course design. In the feedback sessions of the first 2 years, there were several elements of the course that were seen as positive by students, staff, and company representatives alike. Working on a project in robotics that is not fully defined is seen as fun and important. Secondly, students found the variety of projects inspiring. Thirdly, the extensive and timely offered feedback is much appreciated by students. Course staff members can see feedback is being accounted for resulting in improvements. Lastly, students appreciated having to list their personal goals for this course in their report. Since this resides in the very first chapter, they are reading them every time they open their report to work on a new iteration.

3 COURSE EVALUATION 2022-2023

Now that the course is in its third year, and both staff and content maturing within the course, we performed a small study among all students in the course, to see if the students felt the course is now fully fit-for-purpose, constructively aligned, and is helping them prepare for the next more individual phase of their Master’s programme and their future career.

3.1 Research Questions & Methodology

The main research question for this study is: What can be learned from student feedback and perceptions regarding the course’s Learning Objectives and the overall running of the course? An additional research question is: How did the course contribute to your personal and professional development as a future Robotics engineer? After obtaining ethical permission, all 101 students that enrolled in the course in April 2023, were sent a request to part in an anonymous online questionnaire after the end of the course in June 2023. As the researchers are also lecturers in the course, the questionnaire was designed such that no personal identifiable data was collected, and students were assured that their participation was voluntary and in no way affected their grades for the course. A total of 42 students responded resulting in a response rate of 41.5%.

3.2 Results

The results of the survey are informative and somewhat unexpected by the staff. The students are clearly unhappy with the way the project is organized and in particular the workload. Overall the students graded the project 5.2/10 (N=39, SD=1.84). When asked how many hours on average they spent per week on the project (N=39), 67% indicated they spent more than 25 hours per week, with 5% indicating they spent 10-15 hours per week and 28% 20-25 hours. When asked how much time they had expected to spend students indicated an average of 16 hours (N=39 SD=3.96) which was in line with what was communicated to the students. Students were also doing other courses during the project accounting for an average of 8 EC (N=39, SD 4.69). Also, the answers to the open questions clearly indicated that the high workload was really experienced as problematic for the students.

When asked about the organization and structure students are clearly negative with only 30% listing this as positive (See part I, Table 1 in Appendix for detailed results), even though they are positive about the alignment of and information available within the course. Interestingly 26% strongly disagree that the course has the right level of difficulty whilst another 26% agree with this statement. When asked about communication, feedback, and support by staff and clients, students are clearly also more positive (See part II). With regards to the freedom they enjoyed and whether more mandatory moments or more meetings with staff were needed, students overwhelmingly indicated they were happy with the current situation with limited mandatory meetings. There is however, a large minority of students (40%) that would like a weekly meeting with a staff member as can be seen from part III. Students were moderately positive about the attainment of the learning objectives. (See part IV) We also asked how useful students found the workshops and (video) lectures during the course. Students found the company visits really useful, and to a lesser extent the introduction and systems architecture lecture and the ROS and Presentation workshops (See Part V). All others score poorly and seem to be only useful for a few and not for others or may simply be less popular to engage with when under time pressure. Similar scores can be seen in Part VI when asking students about their opinion on the reflection components in the course which varies from mildly positive to very negative especially when it came to the mandatory intercultural peer feedback workshop. Reflection also needs time and mental capacity available to work and be seen as valuable (Hermsen et al 2022).

4 DISCUSSION

It is clear from the results of the study, that action has to be taken to reduce the workload experienced by students and/or increase the number of EC allocated to the course. As the latter is likely unfeasible within the programme at short notice, efforts must be made to identify areas where students spend time unnecessarily. Also, student (activity) monitoring during the project must be increased. Staff were taken by surprise by the hours reported and by the dissatisfaction with the structure and organization of the project as the excessive number of hours or lack of structure and organization never came up in any of the interactions staff had with students during the course. Hence no interventions could be staged. This dissatisfaction likely grew over time coming to a head in the last two weeks. From the reports and self-reflections, it also became clear that some groups went rather overboard by overdelivering on software and robot functionality and using many new (time-consuming) tools to beautify their presentations and reports, while other groups likely lost time due to the breakdown of internal group communications or not asking for help when they were stuck. In addition, this was the first time for students to have to rely on each other's contributions with many in the self-reflections indicating they often still tried to also involve themselves in the work of others which may also have contributed to a higher workload. Yet at the same time students like the freedom and independence they are given during the project. Weekly progress meetings without students being limited in their freedom may aid in being able to intervene when excesses threaten to occur but would increase the staff workload considerably. There is evidence in the open questions that not all students are equally well versed in programming in ROS and that this may also be a contributing factor to some students finding the course difficult, also contributing to the high workload.

In addition, the scheduling is heavily affected by the number of Dutch Public Holidays in that period. Reorganizing the schedule by moving introductory and preparatory activities to the quarter before and creating more online & video resources will limit the number of mandatory sessions and allow each student and group to make use of them on a needs basis and will hopefully lead to a reduction and a more even distribution of the workload as well as room for the necessary reflection. Finally, the project is very reliant on the reliability of the robots and the quality of the simulation environments of the robots. Actions being considered are limiting all industry assignments to use the same simple robot with a variety of manipulators (MIRTE - a TU Delft in-house mini-robot, see mirte.org) allowing each group to have their own robot and manipulators (and have spares) as well as investing in developing high-quality simulation environments that are tried and tested well in time for the project start. It is clear that further research will be needed.

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APPENDIX 1: DETAILED STATISTICAL RESULTS COURSE EVALUATION

Table 1: Detailed statistical results course evaluation. Blue cell indicative of mean and Bold indicates the highest percentage of a statement

		Strongly Disagree	Somewhat Disagree	Neither agree nor disagree	Agree	Strongly Agree	N	Mean	SD
I. Course Organization and Structure	There is a clear connection to prior knowledge	2.38%	4.76%	14.29%	**59.52%**	19.05%	42	3.88	0.85
	The structure and coherence of the course are good	23.81%	21.43%	21.43%	**33.33%**	0,00%	42	2.64	1.17
	The organization of the course is good	16.67%	**33.33%**	19.05%	30.95%	0,00%	42	2.64	1.09
	The content of the course is relevant	4.76%	7.14%	21.43%	**45.24%**	21.43%	42	3.71	1.03
	The course has the right level of difficulty	**26.19%**	16.67%	19.05%	**26.19%**	11.9%	42	2.81	1.38
	The schedule, deadlines, and deliverables are clear	11.9%	9.52%	19.05%	**45.24%**	14.29%	42	3.40	1.20
	The Brightspace page contains all relevant information	4.76%	14.29%	30.95%	**38.1%**	11.9%	42	3.38	1.02
	The manual and the template contain all the necessary information	9.52%	16.67%	23.81%	**45.24%**	4.76%	42	3.19	1.07
	The grading criteria are clear and clearly linked to the LO	26.19%	28.57%	9.52%	**33.33%**	2.38%	42	2.57	1.26
		Strongly Disagree	Somewhat Disagree	Neither agree nor disagree	Agree	Strongly Agree	N	Mean	SD
II. Communication and Feedback by Staff and Client	The communication by staff via email or Brightspace in the course is clear	2.56%	10.26%	10.26%	**64.1%**	12.82%	39	3.74	0.9
	There is sufficient technical support available for the software simulation	7.69%	28.21%	**30.77%**	**30.77%**	2.56%	39	2.92	1
	There is sufficient technical support available for the robots	10.26%	**23.08%**	**23.08%**	**23.08%**	20.51%	39	3.21	1.28
	The Discussion board on Brightspace is a useful place to ask questions	18.42%	10.53%	**50,00%**	18.42%	2.63%	38	2.76	1.04
	The response to questions (via email or discussion board) was timely and of good quality	2.56%	5.13%	33.33%	**41.03%**	17.95%	39	3.67	0.92
	Sufficient and timely feedback on intermediate products is given during the course	7.69%	15.38%	17.95%	**48.72%**	10.26%	39	3.38	1.1
	The Peer feedback in Gitlab is useful	12.82%	23.08%	12.82%	**38.46%**	12.82%	39	3.15	1.27
	It is important to have a real (industry) client	5.13%	10.26%	7.69%	**38.46%**	**38.46%**	39	3.95	1.15
	The client provided sufficient information on the assignment and the robot	12.82%	17.95%	12.82%	**43.59%**	12.82%	39	3.26	1.26
	There are sufficient contact moments with the client	25.64%	28.21%	15.38%	**28.21%**	2.56%	39	2.54	1.22
		Strongly Disagree	Somewhat Disagree	Neither agree nor disagree	Agree	Strongly Agree	N	Mean	SD
III. Independence and Oversight	The current freedom of running the project with only mandatory attendance at workshops, and presentations is fine	10.26%	20.51%	7.69%	**30.77%**	**30.77%**	39	3.51	1.38
	Too many people are not doing enough. Please require attendance during all scheduled sessions	**46.15%**	25.64%	10.26%	12.82%	5.13%	39	2.05	1.24
	Planning and doing everything by ourselves and only receive intermediate feedback on reports and review presentations and get answers to our questions from staff is fine	12.82%	10.26%	20.51%	**30.77%**	25.64%	39	3.46	1.32
	There is insufficient staff support. A dedicated member of staff should meet with each group once a week	23.08%	5.13%	**28.21%**	23.08%	20.51%	39	3.13	1.42

		Not well at all	Slightly well	Moderately well	Very well	Extremely well	N	Mean	SD
IV. Attainment of Learning Objectives	Define a problem definition and its corresponding requirements	12.82%	15.38%	30.77%	**35.9%**	5.13%	39	3.05	1.11
	Design relevant (robot) solutions in the field of robotics by integrating knowledge on opportunities, trends, and societal aspects	15.38%	17.95%	**33.33%**	28.21%	5.13%	39	2.9	1.13
	Produce a robot solution that meets the specifications and considers sustainable, safety, ethical, economics, law, human, and other relevant societal aspects	20.51%	25.64%	**30.77%**	20.51%	2.56%	39	2.59	1.1
	Use functional architecture for planning and communicating robot software	12.82%	12.82%	28.21%	**43.59%**	2.56%	39	3.1	1.08
	Communicate the multidisciplinary robot solution in a clear way, both orally, in writing, and in code documentation	15.38%	10.26%	23.08%	**43.59%**	7.69%	39	3.18	1.2
	Formulate and adjust learning goals on personal development	20.51%	15.38%	**38.46%**	20.51%	5.13%	39	2.74	1.15
	Reflect on one's own competencies (e.g.,Teamwork, Leadership, Entrepreneurial thinking, Strategic multidisciplinary problem solving) and development in these and determine where personal learning goals & interests lie	17.95%	12.82%	38.46%	20.51%	10.26%	39	2.92	1.21
	Show to use feedback to improve one's own performance or the performance of others	12.82%	20.51%	25.64%	**38.46%**	2.56%	39	2.97	1.1
	Apply structured multidisciplinary software project management, with the use of different team roles and responsibilities	20.51%	23.08%	**28.21%**	25.64%	2.56%	39	2.67	1.14
		Not at all useful	**Slightly useful**	**Moderately useful**	**Very useful**	**Extremely useful**	**N**	**Mean**	**SD**
V. Usefulness of Workshops and (video) lectures	Introduction Lecture	5.88%	23.53%	**32.35%**	29.41%	8.82%	34	3.12	1.10
	Company Visit	5.71%	5.71%	25.71%	**42.86%**	17.14%	35	3.51	1.04
	ROS workshop	16.67%	25.00%	25.00%	**27.78%**	11.11%	36	3.08	1.66
	Project Management Workshop	22.22%	**41.67%**	30.56%	8.33%	2.78%	36	2.44	1.02
	Systems Architecture Lecture	11.11%	22.22%	**38.89%**	22.22%	11.11%	36	3.17	1.36
	Peer Feedback Workshop	**50.00%**	25.00%	13.89%	16.67%	0.00%	36	2.08	1.32
	Presentation Workshop	22.22%	36.11%	19.44%	27.78%	2.78%	36	2.78	1.48
	Video Lecture Documentation	25.00%	27.78%	**30,56%**	8.33%	2.78%	36	2.19	1.06
	Video Lecture Action Classes	16.67%	**33.33%**	19.44%	8.33%	5.56%	36	2.03	1.18
	Video Lecture Debugging	16.67%	25.00%	**36.11%**	11.11%	5.56%	36	2.47	1.13
		Strongly Disagree	**Somewhat Disagree**	**Neither agree nor disagree**	**Agree**	**Strongly Agree**	**N**	**Mean**	**SD**
VI. Personal Development	The personal reflection assignment in the course is a good continuation of the Vision and Reflection course	20.51%	20.51%	25.64%	**28.21%**	5.13%	39	2.77	1.21
	Being assigned a specialist role helped me develop a better view of where my strengths and interests lie	25.64%	17.95%	15.38%	**33.33%**	7.69%	39	2.79	1.34
	Being able to try out different team roles, such as coordinator, helped me develop a better view of where my strengths and interests lie	**30.77%**	15.38%	23.08%	25.64%	5.13%	39	2.59	1.3
	The workshop on Peer Feedback helped me develop my reflection and feedback skills	**43.59%**	15.38%	25.64%	12.82%	2.56%	39	2.15	1.19
	Giving and receiving feedback, helped me develop my reflection and feedback skills	12.82%	12.82%	**30.77%**	**30.77%**	12.82%	39	3.18	1.2
	The personal reflection assignment within the project helps me in my personal development toward an independent engineer	**38.46%**	12.82%	17.95%	23.08%	7.69%	39	2.49	1.39