CHALLENGE-BASED LEARNING: IDENTIFYING EXTRACURRICULAR STUDENT TEAMS' DISCIPLINARY LEARNING GAINS

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ABSTRACT

The purpose of this study is to gain new insights into the disciplinary learning gains that students acquire after finishing their participation in engineering-oriented extracurricular student teams. Making these learning gains explicit has the capacity to nurture students' professional identities and enhance their employment prospects in the job market. This study involved conducting group sessions with members of two student sub-teams, both part of one overarching team. Results indicate that students acquired learning gains associated with the hardware manufacturing process, disciplinary design, multidisciplinary design, and utilization of knowledge. Additionally, students reported that they developed learning gains by means of interacting with peers, participating in workshops, and consulting various experts.

KEYWORDS

Extracurricular, Student Teams, Challenge-Based Learning, Learning gains.
CDIO Standards 1,2,3,4,5,7,8,11,12.

INTRODUCTION

Extracurricular learning holds the potential to positively shape students' professional identities and expand their awareness of future career opportunities. To effectively guide students in recognizing and capitalizing on their extracurricular learning, higher education institutions must support students in explicitly articulating these gains (van Uum & Pepin, 2022). However, this task is challenging due to the highly open and self-directed nature of learning in the extracurricular context.

Literature has informed us that students engaged in engineering-oriented extracurricular teams develop competencies emphasized in engineering education, such as specified in the CDIO syllabus (Bravo et al., 2023). Examples of these competencies include personal and interpersonal skills such as initiative, self-awareness, self-confidence, teamwork, and communication (Clark et al., 2015; Larson et al., 2006; Stuart et al., 2011). Furthermore, scholars have emphasized additional benefits relevant to the skills and competencies sought after by the engineering job market and necessary for starting companies, such as enhanced management and organizational skills (Thomson et al., 2013). Additionally, literature has highlighted the development of social networks and improved job market prospects, which are crucial for students' future career success (Stuart et al., 2011). Nonetheless, limited research exists on disciplinary learning gains within the context of extracurricular student teams addressing socio-technical open-ended challenges where students are in the lead of the project. This study seeks to acquire new insights on the learning experiences of students involved in extracurricular engineering-oriented student teams and their contribution to the acquisition of disciplinary learning gains.

THEORETICAL FRAMEWORK

Qualitative insights into perceived changes in students' learning can offer relevant insights to both students and higher education institutions regarding the value of participating in engineering-oriented extracurricular teams. To capture these insights, we must initially establish a clear definition of what constitutes a change in learning, i.e. a learning gain.

Pampaka et al. (2018) suggested that a learning gain is what is learned between two or more time points. In a more detailed definition, McGrath et al. (2015, p. xi) define learning gain as "*the 'distance travelled,' or the difference between the skills, competencies, content knowledge, and personal development demonstrated by students at two points in time. This allows for a comparison of academic abilities and how participation in higher education has contributed to such intellectual development.*" In this study, the definition proposed by Vermunt et al. (2018, p. 272) was chosen because it allows to capture the diverse types of changes in learning that can be acquired during the participation in an extracurricular engineering-oriented student team. They define learning gain as "*a student's change in knowledge, skills, attitudes, and values that may occur during higher education across disciplines.*"

Various methods assess students' learning gains, including empirical observations, surveys, rubrics, and self-report questionnaires. Self-reports foster self-reflection and enhance learning by promoting self-monitoring habits. However, relying solely on self-reports has limitations, such as potential overconfidence in knowledge and subjective comparisons of perceived learning gains. In this study, we utilized self-reports because our emphasis is on the process explanations for students' acquisition of learning gains and their types rather than the depth of the learning experience.

In this study, the CDIO Syllabus Revision 3.0 was chosen as the framework for conducting thematic analysis of students' self-reported learning gains for two primary reasons. Firstly, the CDIO syllabus provides comprehensive descriptions of learning outcomes across fundamental knowledge, personal and professional skills, interpersonal skills, and the innovation process. Secondly, the expansion section describes learning outcomes associated with leading engineering endeavors, entrepreneurship, and research (Malmqvist et al., 2022). These elements aids in categorizing what students self-report regarding their extracurricular experiences given the characteristics of extracurricular projects undertaken by student teams at TU/e and TU/e innovation Space's focus on fostering expertise in technology-based innovation and entrepreneurship.

CONTEXT OF THE STUDY

TU/e innovation Space is the center of expertise for student entrepreneurship and challenge-based learning (CBL) at Eindhoven University of Technology. In CBL, students tackle real-world challenges as teams. They have the freedom to design and direct their own projects, which fosters self-directed learning. This approach empowers students to acquire the necessary knowledge and skills for successful problem-solving (Doulougeri et al., 2021).

TU/e innovation Space student teams program provides support to approximately 650 students who participate in extracurricular teams to address global socio-technical challenges in collaboration with external entities such as companies, societal organizations, and research institutes. These teams are heterogeneous, including members from various academic programs, educational levels, and nationalities. Their commitment varies, depending on personal availability and motivation. Teams shape their organizations to reach unique goals. Their technological projects cover a wide spectrum, ranging from technological divulgation to the development of cutting-edge technology. One of the most important drivers is students' intrinsic motivation. Furthermore, participation is voluntary, stimulated by a shared sense of purpose. Finally, TU/e innovation Space provides coaching, technical expertise, physical infrastructure, and counsel on financial and legal aspects.

Teams are structured based on sub-teams that handle specific tasks that can be, among others, technical, managerial, communicational, etc. The objective of the sub-teams is to work effectively. It implies that members acquire specific knowledge, attitudes, skills, and competences that help the team reach its goals. The sub-team is the basic work cell that contributes to achieving the overarching goals. Furthermore, team knowledge and experience are developed and contained in these units, and from there they are spread across the team.

RESEARCH QUESTIONS

In this study, we are interested in the types of learning gains that the students acquire and the processes that enable them. Therefore, the study addresses the following two research questions: Q1) What disciplinary learning gains do students acquire during their participation in an extracurricular engineering-oriented student sub-team? Q2) How do students develop these disciplinary learning gains?

METHODOLOGY

Participants

In this study, a volunteer student team named Ice (pseudonym), took part. Its goal was to design, build, and test a solar-powered, self-driven Antarctic research rover (See Appendix A). Two of its sub-teams participated in this study. These were: Nomad sub-team, comprising four members, all part-time, with a background in mechanical engineering, was tasked with the design and construction of the rover's chassis. They were responsible for integrating components designed and built by other sub-teams. They resolved interface issues, such as determining how to securely attach solar panels to the chassis or finding suitable space for installing batteries and cables. In addition, they were responsible for ensuring the structural integrity and functionality of chassis components. Transmission sub-team, comprising of three part-time members with backgrounds in electrical and mechanical engineering, was focused on capturing, storing, and transmitting energy to the rover's transmission. Students selected batteries and ensured the energy delivery to the transmission. Also, this sub-team encountered challenges in maintaining optimal battery temperature and preserving the efficiency of the solar panels. They were also tasked with addressing interface requirements with the chassis and control electronics.

Data collection

This study focused on collecting teams' insights regarding learning gains during a 90-minute artifact analysis workshop. The workshop was audio recorded and commenced after participants had given their consent to participate. During the workshop, sub-teams engaged in reflection on the systems and components they had designed and constructed. These artifacts were utilized throughout the workshop to enrich the discussions.

To facilitate further, a purpose-designed board with three sections—triggering factors, critical steps, and learning gains—was used (see Appendix A). In the first section, triggering factors, students detailed what they wanted to know and the knowledge they previously had to address the project technical challenges. In the second section, critical steps, participants explained the process they followed to achieve the project's goals. Participants also recounted learning events and identified means that supported their learning, adding depth to their understanding of the process. Finally, participants identified the learning they acquired through their participation in the sub-team. Students used post-its, notes, drawings, or artifacts to provide more details.

DATA ANALYSIS

The data obtained from the artifact analysis workshops were analyzed focusing on coding students' quotes related to learning gains. This iterative process involved refining the code list, incorporating new codes, and adjusting the coding strategy. The initial step involved reading the entire dataset without applying any codes to gain a comprehensive understanding of the data. Learning gains were considered only when students explicitly mentioned gaining insight into their performance or mastering competences, following a methodology similar to Bakkenes et al. (2010).

Learning gains were coded and classified according to the main categories established in CDIO syllabus 3.0. These are: fundamental knowledge and reasoning; personal and professional skills and attributes; interpersonal skills; the innovation process; and leading engineering endeavors.

RESULTS

The following paragraphs detail the insights shared by both sub-teams during the sessions. We first described what the sub-teams learned and then how the sub-teams learned.

What students learn

Nomad sub-team wanted to learn how to increase the modularity and stability of the chassis. It involved working with diverse materials and integrating engineering knowledge to enhance functionality. The team also wanted to learn how to transform raw materials into purposeful components. Finally, they wanted to learn how to use power tools.

The sub-team members indicated that they entered the project with an understanding of the content covered in the first-year mechanical design course and the experience of designing and building a model crane using L-shape steel profiles for its structure.

Upon reflecting on the processes carried out by Nomad sub-team, members articulated significant learnings. First, they emphasized that they learned the importance of thoughtful consideration before implementation (Innovation process: Consideration of implementation and operation), underscoring a key takeaway: they learned the relevance of the conscious evaluation of how potential implementations of components or subsystems can influence the overall vehicle functionality. For example, students indicated the cooling system critical event:

> *"When the motors finally got working, they ran at like max speed for half an hour. And they got up to 90 degrees. Which is pretty warm. Especially when they are in a closed capsule. So then someone said, You should have a cooling system. And okay, we should make a cooling system. The only thing we could think of was air cooling."*

To address this challenge the students decided to implement some vents in the back and the front of the chassis to allow air circulation to cool the electronic components. After the implementation of the solution, they become aware of its impact. They indicated:

> *"Then we said, oh no, we have holes in our vehicle. After some thinking, we realized that it's not that big of a deal if we left hot air inside to get up to like 90 Celsius degrees in such a cold temperature, because of all the cooling snow around. We cut those holes for nothing and we spent a lot of time trying to come up with ways of ensuring that air can get through, but water can get through too. That was definitely an experience that we had to have. So, definitively, we learned."*

Contrary to the initial assumption of a linear design and implementation process, the sub-team discovered that the design process is iterative and involves, among others, observation, reflection, analysis, and actions such as prototyping and performing calculations. (Innovation process: The design process phases). At the beginning, the students indicated that when they had an idea, they just implemented it in the vehicle, and then they analyzed if the idea produced the results they expected. Student B indicated that for a lot of parts of the vehicle they just implemented design and construction actions and afterwards they thought about its impact.

However, after several situations where they didn't achieve the expected results, they became aware of the importance of analyzing the solution implications in other components. In this regard, they indicated:

> *"There was a moment when we just stopped and thought for a second. it was really like, we should really make some calculations because we know this!, and that helped out quite a bit. If you want to stop the bending chassis we have to use the L profile, because it stops the momentum…and we knew the physics behind it"*

In addition, the team found value in integrating learning experiences such as the ones from their first design-based learning course (Innovation process: Utilization of knowledge in design). Students expressed awareness of the fundamental principles of solid mechanics governing the behavior of a steel L-shape profile. Consequently, they opted to assemble these profiles in a manner that optimizes their mechanical properties, particularly in terms of resisting torsion and flexion, thereby ensuring the structural integrity of the chassis.

Also, connected to the implementation of the L-shape profile chassis, the sub-teams indicated that they gained proficiency in the use of metal-mechanical tools (Innovation process: Hardware manufacturing).

The interconnectedness of diverse elements within the project became evident, prompting a broader perspective on system integration. The realization that systems are integral parts of a larger whole underscored the importance of considering the broader context in problem-solving and decision-making (Innovation process: trade-offs among various goals, function, concept, and structure). In this regard, student A expressed:

> *"So, if you really want to make this aerodynamic, then you would make it really small like it basically looks like a bullet. But then how do you fit some of the stuff inside? Same thing with making it structurally stable. You would make it out of pure steel, like no sandwich boards. But then you just sink into the snow. So there's some optimal weight…and that's kind of the fun part of trying to figure out where that is and what we would sacrifice for it."*

In the case of the Transmission sub-team, its members expressed that they wanted to learn about electric mobility. Specifically, they expected to learn about how electric transmission components are made and how the power is controlled when transmitted to the wheels. In addition, the students expressed they wanted to learn how to capture, store, and distribute electricity in a solar vehicle. Lastly, the sub-team emphasized that they wanted to acquire practical technical knowledge on hardware manufacturing.

Students reported that they knew some information about Antarctica's site conditions. They highlighted factors such as temperature range, humidity levels, and variations in sunlight hours throughout the year. Moreover, they had a basic understanding of how these environmental variables influence the design requirements for the rover, such as the necessity for sustainable energy usage and the implications of temperature and light exposure on the battery system. Additionally, they expressed a basic knowledge of electric powertrains, based on both their coursework in mechanical engineering and supplementary information from online sources.

The students reported that after their participation in the sub-team, they acquired learning gains in several sub-categories of the CDIO syllabus. Regarding the manufacturing process, they indicated that they acquired knowledge and experience in new soldering techniques for electrical cables and also learned about electrical cable physical restrictions (Innovation process: Hardware manufacturing). For example, student C indicated the following:

> *"We learned about how the slack of a cable could be very useful at times. We had a too-tight cable. And later, because we wanted to make the backplate stronger, we put an iron bar on it to enhance it. What happened was that this slack of the cable was gone at that point, because now there was a bar pretty tight. And what happened was that, at some point, because of the bar, the cables broke completely. So we learned that slack is important."*

In addition, they reported learning gains associated with increased understanding of the design process and its stages (Innovation process: Design phases). For instance, the students indicated:

> *"The process of designing or building something begins with initial research and ideation, mapping out the entire process from concept to product. I've personally experienced this entire process multiple times, acquiring a good understanding of how to progress from an idea to the final product in a structured manner."*

Also, they indicated that they became aware of the relevance of the design process and the relevance of the purpose of the design (Innovation process: The design process)

> *"I think we learned the importance of researching and designing, which was sometimes skipped a little bit and let the first solution be taken, and then we discovered that it didn't really work."*

Finally, they indicated that they acquired new engineering knowledge about energy storage systems, which was not part of the contents covered by sub-team members previous courses (Fundamental knowledge: Engineering knowledge) and also gained awareness on avoiding overengineering components and systems (Innovation process: Requirements of elements and components). Student D indicated:

> *"The simple thing works the best, and don't overengineer or overcomplicate things; don't look for this shiny way of doing things."*

How they learn

In order to answer the second research question, both teams were asked to describe the process they followed to achieve their goals. Students indicated that company advisors, external advisors who belong to research institutes both internal and external to the TU/e, technical advisors from TU/e innovation space, and peers influenced their acquisition of learning gains. These resource persons transferred technical knowledge, experiences, and they provided feedback on design and implementation aspects, specifically materials, manufacturing process, and technical aspects on the site conditions in Antarctica. For instance, student A, from the Nomad sub-team, chassis, indicated that they received advise from an architect who works in a research facility in the Antartica:

> *"So he has a lot of knowledge about the building, but also about the site conditions. When we were talking about thermodynamics, he was very knowledgeable about the way the station works—it is abandoned in winter. So we have to make sure that all the core systems stay alive during the winter months. They put things in the*

> *middle of the physical center of the station because it takes longer for that to cool down. And just things like that are also something that's a huge resource that experts have."*

In addition, both teams indicated that they followed different approaches to address project's challenges and consequently to acquire learning gains. Based on the sub-teams' reports, different work processes were executed depending on the system they had to design, manufacture, and test. For example, Nomad sub-team indicated that they follow a trial and error approach when finding the right structural stability once the solar panels were installed on the chassis. Students indicated that due to their time restrictions they didn't have the time to think in a detailed way about the solution:

> *"It was a trying solution; It is one of those systems where you could add more to it because we were just reinforcing."*

Transmission sub-team followed a different approach that included first researching, ideating, integrating previous knowledge, and then testing. After observing the results, they took corrective actions, in the case the results were not satisfactory, and then they tested again.

DISCUSSION

The insights gathered from the sub-teams show the diverse learning gains acquired throughout the project's duration. Nomad sub-team reported learning gains associated with the innovation process. Their recognition of the significance of thoughtful consideration before implementation represents a substantial realization. This strategic perspective emphasized the crucial role of pre-implementation evaluation in shaping overall vehicle functionality. Furthermore, Nomad sub-team's increased acknowledgment of the iterative nature of the design process, involving observation, reflection, analysis, and actions such as prototyping, deepened their understanding of the innovation process. In addition, the integration of experiences from their initial design-based learning course, particularly in applying knowledge to design, demonstrated them a practical application of academic knowledge. Finally, Nomad sub-team increased their awareness of the interconnectedness of diverse elements within the project, prompting a broader perspective on system integration.

Transmission sub-team's increased awareness of the environmental conditions in Antarctica and its technical challenges indicates a proactive approach to project considerations. Their concerns about battery system operation in low temperatures increased the practical understanding of real-world challenges and the need for innovative solutions. Also, they reported learning gains connected to a hands-on approach to hardware manufacturing such as mastering new soldering techniques, understanding electrical cable physical restrictions, and increased insights into the design process stages. Additionally, the acquisition of new engineering knowledge about energy storage systems and awareness to avoid overengineering demonstrate a broadening of their disciplinary learning gains.

The responses provided by both teams shed light on the intricate process through which students develop disciplinary learning gains within the context of their extracurricular engineering-oriented projects. Addressing the second research question (How disciplinary learning gains are developed) reveals a dynamic and collaborative approach influenced by various advisors and peers. In this regard, the involvement of company advisors, external advisors from research institutes, technical advisors from TU/e innovation space, and peers significantly impacted the acquisition of learning gains. These played a crucial role in transferring technical knowledge, sharing experiences, and providing valuable feedback on design and implementation aspects. The specificity of their contributions, particularly in areas such as materials, manufacturing processes, and considerations related to the challenging site conditions in Antarctica, underscores the multidimensional nature of the learning process.

Furthermore, both sub-teams highlighted the adoption of diverse approaches to address the challenges and, consequently, to acquire learning gains. Nomad sub-team's utilization of a trial-and-error approach, especially in determining the structural stability after the installation of solar panels on the chassis, exemplifies a pragmatic method within the constraints of time. The acknowledgment that detailed thinking might be limited due to time restrictions highlights the need for adaptive problem-solving in real-world scenarios. In contrast, the Transmission sub-team opted for a more systematic approach involving research, ideation, integration of previous knowledge, and testing. This methodical process allowed for a structured examination of results, enabling them to take corrective actions and iterate on their designs when necessary. The emphasis on testing as an integral part of the process aligns with a continuous improvement mindset, reflecting a commitment to refining solutions based on observed outcomes.

CONCLUSIONS, LIMITATIONS, AND FUTURE RESEARCH

In conclusion, both sub-teams exemplify the integration of theoretical knowledge and practical skills within the CDIO framework, showcasing the benefits of challenge-based learning. The recognition of the interconnectedness of elements, iterative design processes, and the application of engineering principles to real-world challenges underscores the richness of the learning experiences within these extracurricular projects performed by student teams.

In addition, the development of disciplinary learning gains among students participating in the sub-teams is a collaborative and multifaceted process. The influence of diverse advisors and peers, who contribute technical knowledge and experiences, highlights the importance of mentorship and collaborative learning. The sub-teams' adoption of varied approaches to address project challenges demonstrates adaptability and problem-solving skills within the constraints of time and resources. In parallel, the two sub-teams used different approaches: the pragmatic trial-and-error approach by Nomad sub-team and the systematic research-ideation-testing cycle employed by Transmission sub-team. Together they showcase the flexibility required in complex engineering projects. These diverse methodologies contribute to a comprehensive learning experience, encompassing both theoretical knowledge and practical problem-solving skills. The findings underscore the significance of experiential learning, and adaptive strategies in fostering the development of students' disciplinary learning gains in real-world engineering challenges. Producing an artefact provided numerous incentives to rethink their approach in solving their challenges.

A limitation of this study arises from conducting the session exclusively with two sub-teams within the same overarching team, constraining the diversity and quantity of learning gains identifiable among students. This limitation extends to the various ways in which students learn within a sub-team. Therefore, it is recommended that future studies involve diverse teams with varying structures, distinct projects in terms of objectives, and unique technical challenges. This approach aims to unveil a broader spectrum of learning gains and diverse approaches for addressing technical challenges, ultimately fostering different methods of acquiring learning gains. In subsequent studies, we aim to explore how work processes, employed to tackle technical challenges, influence the types and quantities of learning gains acquired by students.

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BIOGRAPHICAL INFORMATION

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Appendix A – Sub-team disciplinary learning reflection board and artifact pictures

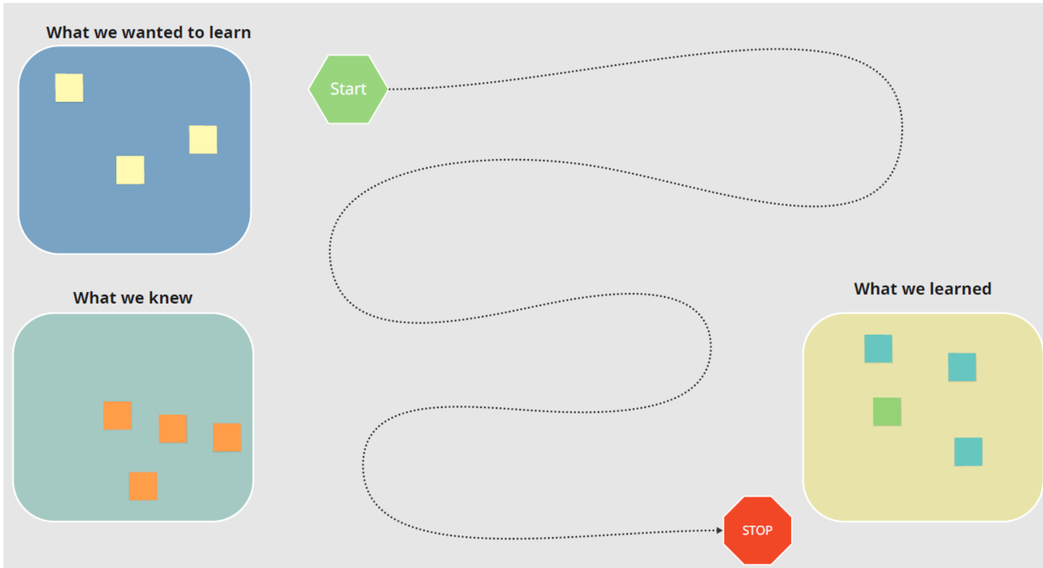

Figure 1. Reflection board

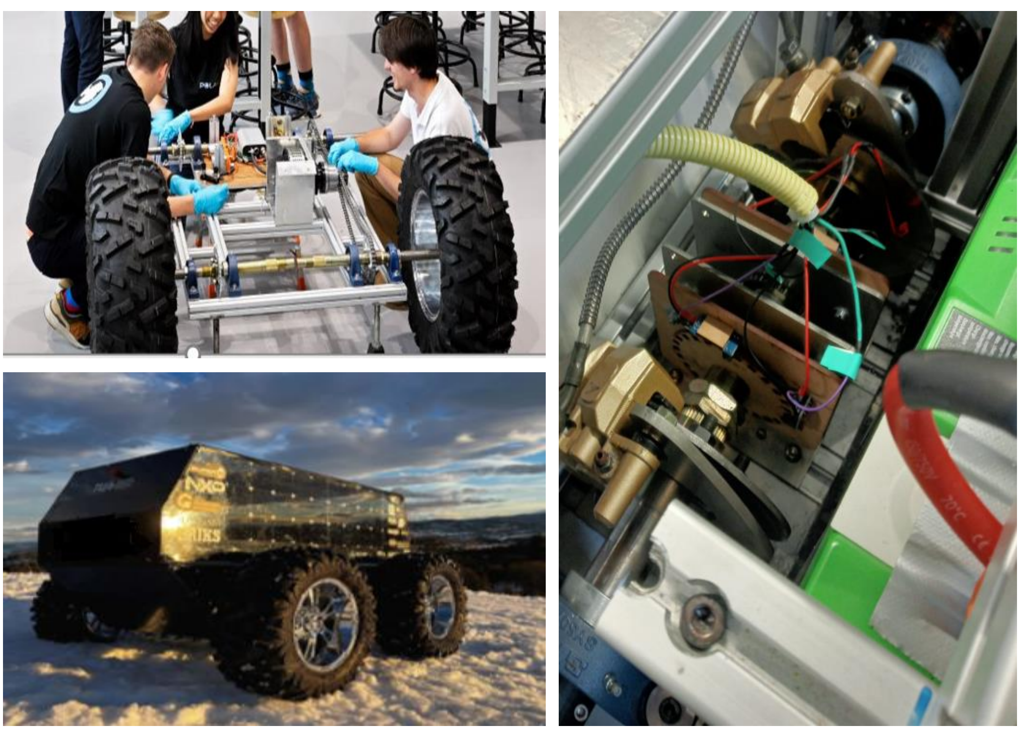

Figure 2. Team Ice's rover