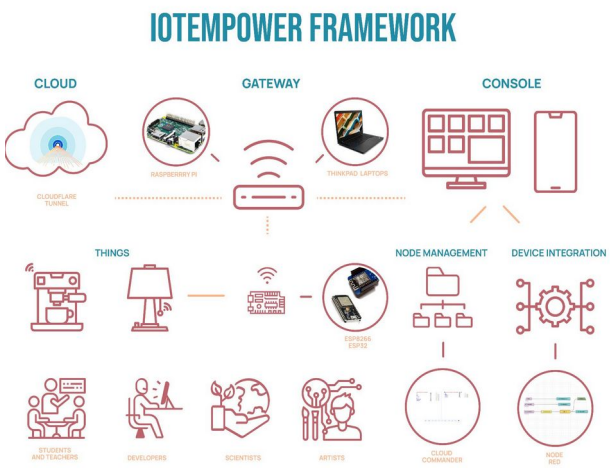
The Internet of Things

Empowering Creativity and Innovation in our Students the IoTempower Way

Course Summary:

Our course, “The Internet of Things,” is an engaging, hands-on course that bridges the virtual and physical to impact positive change. The course can cater to different learning needs with flexible formats: Express (4h) Workshop, Intensive (16h) Workshop, and Full Course (60h guided, 20-40h unsupervised). Starting from the 16h version, we cover core topics of storytelling, basic electronics, IoT architecture, machine-to-machine communication, and exploring open-source IoT integration using Node-RED, all within our fully open-source and in-house developed IoT teaching framework - IoTempower.



Images from flaticon pack.

IoTempower facilitates rapid prototyping, easy integration, system building, and device management. Our course addresses real-world 21st-century challenges by integrating various fields such as computer science, engineering, data analytics, design, storytelling, and interactive arts into our curriculum. We encourage collaboration through group projects and lab tasks, while our teaching approach emphasizes research and exploration for the students. We provide a learning environment that allows controlled failure and refinement to cater to the creative development of the learner. Our diverse student body facilitates intercultural and international learning, international guest speakers from industry and academia, and regular exchanges with other university programs and teachers, including ENLIGHT partners. We employ challenge-based education, where students solve and select real-world IoT problems, enhancing their learning experience.

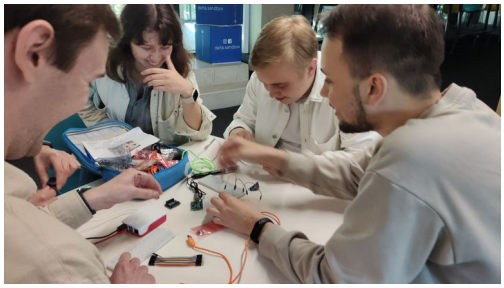
Team lead: Prof. Dr. Ulrich Norbisrath: Associate Professor at the University of Tartu in Estonia, independent IoT consultant, and inventor. He has more than 25 years of industrial and academic experience in Software Engineering and Systems Integration, supported the start-up of several software development companies, and consulted tech companies on questions of Systems Integration, Internet of Things (IoT), and Cloud Computing. He raised significant grants on Creativity in Education, Cloud Computing, and High-Performance Computing at universities in Europe and Central Asia. He taught at universities in Estonia, Germany, Austria, Brazil, Indonesia, Kazakhstan, Singapore, and the US. He is a published book author in Software and Requirements Engineering. His current research focuses on the Internet of Things (IoT), making IoT and developing IoT systems easily accessible across all its application domains. *Email*: ulrich.norbisrath@ut.ee

Assistant: Renato Perotto is a visual artist from Brasília, Brazil. Bachelors in Fine Arts and Master of Design from the Federal University of Brasília, Brazil. He is a junior researcher and PhD student at the Department of Computer Science at the University of Tartu, Estonia. In his research, he explores different multi-media forms, from analog photography to digital, video, documentary films, virtual reality, electronics, and computer-generated arts. He is also interested in how arts appropriate these technologies and how the creative process can help us better address IoT education. *Email*: renato.perotto.machado@ut.ee

Assistant: Matevž Borjan Zorec is skilled in hardware and software engineering, focusing on positive user experience design, automation, robotics, and machine learning. With a background in electrical and robotics engineering, his master's thesis concentrated on innovative open-stack teleoperation teaching solutions. He contributes to IoTempower as a teaching assistant and developer. *Email*: matevz.borjan.zorec@ut.ee

Portfolio - The Internet of Things

Empowering Creativity and Innovation in our Students the IoTempower Way



Our course fits the ENLIGHT Teaching and Learning Award, centering on empowering students through hands-on Internet of Things (IoT) engagement, fostering creativity and innovation. We advocate that challenge-based Education (CBE) allows students to work with the technology themselves and apply it to real-world problems. Our students have a chance to truly understand IoT's strengths and weaknesses and its potential to help us deal with today's challenges in creative, innovative, collaborative, and communicative ways. We foster an inclusive course mindset, promoting challenge-based education, storytelling, exploration, and working with failure as part of the learning process. We emphasize collaborative team and group work and encourage critical reflection, with no differentiation between labs and lectures. From the start, students experiment with hardware, programming, and networking aspects of IoT, bridging the gap between the virtual and physical worlds through prototyping. We discuss real-world impacts, integrating projects and challenge-based learning with industry lectures and stakeholders' input. By constantly developing our teaching tools and framework, we incorporate design processes that focus on teachers-as-learners and are inspired by the learn-by-doing mindset, where knowing and doing are inseparable parts of the learning experience process.

In our course, students cultivate a comprehensive understanding of IoT with network and cloud computing technologies in creative ways and how they can be applied to real-world challenges. We highly focus on practical skills through challenges related to outfitting physical objects with networked sensors and actors and proficiency in developing code for data collection, visualization, analysis, and actuation in the physical world. Furthermore, students experience designing, implementing, and testing IoT systems and integrating sensors, wireless connections, and actuators. Finally, students demonstrate their understanding and application of IoT systems through various projects, a portfolio, and presentations, where they will defend their stories, designs, and implementations. We are calling this thinking in systems "Putting the S back into the Internet of Thing(s)", differentiating ourselves from IoT classes that only make the students master one device and connect that to cloud services in the internet. We facilitate students to build systems that are more than the sum of their parts.

This course originates from the "Home and Building Automation" class of spring 2015 at the University of Applied Sciences Upper Austria in Linz. Since 2016, we have been augmenting and transferring parts of the course into its own IoT introduction course. We developed all supporting software in-house at the public GitHub repository: github/iotempire/iotempower. The course, in its various formats, has been taught in Estonia, Germany, Austria, Brazil, Singapore, Indonesia, and the US. It has catered to diverse audiences, from university and school students to professionals in the arts and industry sectors. This global exposure has contributed to the continued growth and refinement of both the software framework and the teaching methodology. Its approach to portfolio-based assessments and contract-based grading focuses on project-driven modules and enables evaluations to be either graded or pass-or-fail. Pass-or-fail has become the preference since it has led to higher student engagement and achievement.

Course Elements

The core sessions include storytelling and story-driven development, basic electronics, networking, communication protocols, IoT architecture, and exploring open-stack integrations using Node-RED, all seamlessly enabled within the umbrella IoTempower framework. All the software used in our course (including the IoTempower framework itself) is open-source and relies only on libraries with permissive licenses, making it a solution that is affordable and easy to replicate. Our students can even turn their projects into commercial products without any license restrictions.

We employ contract-based assessments, where students investigate and propose the scope of their deliverables. Students grow ongoing project documentation of their individual (reflective), pair-, and teamwork using their own GitHub repositories as portfolios. This approach is a well-appreciated documentation method, as portfolios are also invaluable for individual students for later reference. Furthermore, it allows the students to improve their documentation and version control skills, which are industry-standard for collaborative work in the tech field. Portfolios also enable more exploration-valuing assessments: you can give students points if they attempted a task and engaged long enough with it - completion is not required, though usually achieved. Finally, the portfolios allow easy presentation, accountability, and assessments. Furthermore, they allow the students to give personal feedback to their instructors much more accessible than in traditional lecture and quiz-based courses.

In a long (>60h) class, we currently have 6 modules: (1) Defining IoT and Story-Driven Development, (2) Basic Electronic Prototyping, (3) Your Own Network Infrastructure, (4) IoT Communication and Integration, (5) IoT Frameworks and Multi-Device Management, (6) Advanced IoT, and a final project. Each module gives 1 to 2 points, the final project 5, and the personal reflections in the portfolio 3, totaling 18 points. For the first modules the students receive template contracts that they can modify. Contract templates become less restrictive and give more choice the further we are progressing in the class. In a pass-or-fail setting, the students pass with >10 points, else the 18 points can be used for differentiated grading. The modules are carried out in groups of 2-3, the final projects in groups of 4-6, and personal reflections are always individual.

We introduce the IoTempower framework early in the class to allow rapid prototyping and quick success, which keeps students motivated to learn more. Once the students have experienced key IoT development tools (after about 50 to 70% of the class), they start designing and then implementing their final project. Starting from stories, students describe a challenge inspired by a real-world problem and work towards constructing a feasible solution. We are trying to encourage the story and challenge development from the beginning, but it depends on the type of student and how deeply they commit to the storytelling part of our IoT class. Students need to engage in both technical but also design challenges.

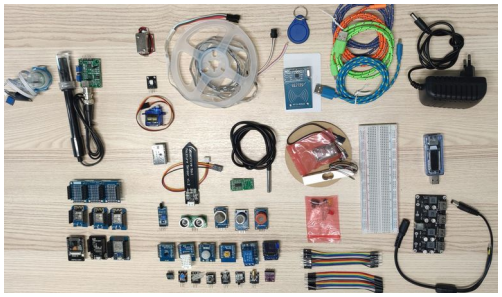
Finally, we invite guest speakers from industry and academia to highlight different problem domains to help guide the students in picking and describing challenges for their final projects. For example, guests touched on Environmental Engineering and Data Science, how mobile infrastructure can drive IoT solutions, and how IoT devices can be used to monitor factory floors for predictive maintenance.

Learning Tools

We provide a chat server that allows all students studying IoT to profit from each other across university and country boundaries. After several tries and discussions with students we use Discord in the Tartu, Linz, and Regensburg case and open that for any teacher else approaching us. However, other chat environments should work as well but will lose the networking effect with other students and teachers being involved in IoTempower.

We also provide slides, task descriptions, questions, and videos to help with technical challenges or supporting discussions. We are continually creating new video material to support upcoming technical challenges. Chatbots of large language models (LLMs) like ChatGPT, Copilot, or Gemini also enhance our class learning experience by speeding up individual and team in-class research tasks. They also enrich our discussions by allowing us to critically reflect on their answers and suggestions.

In our course, we embrace the idea that hands-on experiences are crucial for the learning process. We provide a kit with sensors, actuators, cables, power supplies, a gateway, and microcontrollers to each student team. We paid special attention to selecting each kit component, prioritizing affordability and ease of sourcing in most regions worldwide. We are particularly proud of this aspect of the framework and kit because it makes it optimal for prototyping and teaching, even if resources are limited, supporting disadvantaged communities and emerging economies alike.



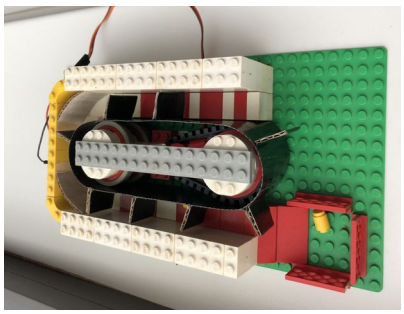
The hardware kit and the framework deliver a complete and portable network infrastructure. Students can accomplish all class projects and tasks with the kit's contents. The gateway is a genuinely innovative aspect of this specific combination of framework and kit. In some course settings, students

can deploy the gateway using a single-board computer like the Raspberry Pi or Atomic Pi. In others, they can reuse old upcycled laptops, smartphones, or simply affordable OpenWRT routers - depending on the resources available at the respective location. The gateway functions as an access point and a service provider for networking and integrating the nodes and endpoints. Students can configure their networks with multiple internet connection solutions, such as USB smartphone tethering, WiFi repeater, or Ethernet cables. This flexibility facilitates internet access to the IoT systems in regions where this might take time to accomplish.

We found this approach equips each team with a truly practical experience as they can control every aspect of their network and do not have to depend on resources and services (from the university or the cloud) outside of the scope of their group. This characteristic also comes in handy when teaching workshops and short courses in places with limited infrastructure. Both the gateway and the IoT kit function as social-material devices that broaden the opportunity for interaction between students and the learning community. They are platforms for sharing services, resources, problem-solving, and learning experiences for challenge-based projects, as further elaborated in [Machado2024].

We ran surveys with students during the Spring 2023 and 2024 courses at the University of Tartu and learned that by sharing the IoT gateway, classmates enhanced their learning experience. The core of our IoT hands-on education is the ability for students to deploy their own infrastructure to collaborate with their teammates in a challenge-based project. More than half of the students strongly agreed, and more than another quarter somewhat agreed with the statement: “Collaborating with others was important for my IoT learning experience.” One student commented: “Sharing with other people gave us the opportunity to learn from each other by fixing errors or even by observing different methods for solving the same issue.” Students and educators can submit issues to IoTempower’s central repository. These issues are available for students to take as a challenge, as thesis or project topics. Finally, staff and students use the IoTempower framework and kit beyond the educational setting, with deployed solutions in agriculture, interactive arts, home automation, and logistics.

Impact



On https://iotempire.net/projects/ we list several real-life based stories of how our IoT course has creatively empowered students and educators in the realm of the Internet of Things to develop innovative solutions. We want to point out two student[1] stories and a teacher story. In the first, Toby ends up building a prototype for better eldercare in nursing homes. Initially slightly confused about the modern learning style with portfolios and a flipped classroom, he quickly engages and enjoys prototyping a solution that connects with the experienced needs of a family member. His teammates and he developed a walker prototype with falling-over detection, a notification system, a pill dispenser, and an emergency situation detection with the provided kit. Toby and his team presented great solutions to a real world problem applying IoT, so they passed our course with honors.

The second story describes an international master’s student Karli from our recent Internet of Things course in spring 2023. At the beginning of the course, Karli applied the skills learned in our Internet of Things course to create a home automation system for their apartment and later, a smart planter box that they named HarvestMate for their final project. HarvestMate is a box equipped with various sensors and services using the IoTempower framework, which measures natural light, water levels, soil moisture, air temperature, and plant growth, adjusting artificial light and watering as needed and providing data visualization and notifications. This practical application of course content not only solved real-world problems but also demonstrated the portability, affordability, and versatility of the IoT kit and software. Their project was demoed at the University of Tartu IT Academy summit and at the UT CS students competition. During

1 The names of the students are redacted. The projects are real. We have consent of the students presenting these projects.

the IT Academy, the startup Stagnationlab showed interest in partnering with students and working on a product prototype. Also, other faculty members and students were interested in having a HaverstMate for their homes and offices.

In the teacher's story, Ruben, an IoT professor at OTH Regensburg, Germany, adopted our publicly accessible IoT teaching materials and framework for his own course in Spring 2023. He found that using the Raspberry Pi as a mobile gateway facilitated hands-on lab work and group collaboration, and he successfully implemented the flipped classroom model and integrated lecture/lab sessions. Ruben also adopted our approach for final project presentations and contributed to the IoTempower framework by adding support for Apple hardware, demonstrating the adaptability and community-driven growth of our teaching resources.

The stories of Karli, Toby, and Ruben demonstrate the transformative impact of teaching our IoT course. Karli's and Toby's stories illustrate how students can rapidly apply classroom knowledge to real-world problems, fostering engagement, creativity, and practical problem-solving skills. Ruben's experience highlights the adaptability and accessibility of our teaching material, enabling educators to facilitate hands-on, collaborative learning experiences. The high student retention in our courses and the widespread use of the IoTempower framework and kit in personal projects underscore the engaging, effective nature of this teaching approach. Collectively, these stories attest to the power of the IoTempower way in cultivating a deep, practical understanding of IoT.

Conclusion

Our course is aligned with the ENLIGHT mission as it is creative, challenge-based, collaborative, multidisciplinary, hands-on, and empowering for students and educators. The portable and mobile characteristics of the learning tools that we developed are a truly innovative approach to IoT education. It allows our course to adapt to different formats and challenges of today's education, making it possible to be taught in other institutional settings and timeframes. We hope we are well suited for this award as it will bring great visibility to our course at the ENLIGHT Teaching & Learning Conference. It is most welcome as it will help us motivate other teachers and students to join our community of learning IoT in a hands-on and impactful way and continue to improve this course even further.

Resources and References

[Machado2024] Machado, R.P., Norbisrath, U., Jubeh, R.: *IoT educational framework case study: Devices as things for hands-on collaboration*. Journal of Engineering Education Transformations (37) (2024)

- IoTempower, software that facilitates all this with lots of documentation and also starting points for teaching, can be found at https://github.com/iotempire/iotempower
- The full stories describing our impact: HarvestMate, SmartNursing, Teaching
- More technical description of the used hardware of the kit: https://ulno.net/iot/devkits/
- Teaching material (Syllabus, Slides, Contracts, Tasks), videos, playlist
- IoTempire discord server: https://discord.com/channels/1064132619735928932/1064132620398637148

Acknowledgments

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