DESIGNING PROBLEM-BASED LEARNING CASES TO FOSTER STUDENT ENGAGEMENT IN STEM

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ABSTRACT

We all recognize the effectiveness of problem-based learning (PBL) in engaging everyone and helping students develop critical thinking and teamwork skills. PBL was developed to make medicine students ready to work under real life conditions. Therefore, since the 50s there have been several cases for medicine scenarios being published. In the STEM field it is still not common to use this method, which is quite unfortunate. Therefore, we have chosen to share how we implement PBL to teach Communication Networks to master's students.

In this paper, we will present our experiences in designing new PBL cases, alongside feedback from our Center for Teaching and Learning (ZLL). These cases reflect current trends in key topics related to communication networks, our engagement strategies, and the student feedback we have received during the winter semester 2024/25.

Keywords: PBL, engagement strategies, teamwork, communication networks, international student groups

1. INTRODUCTION

Problem-based learning (PBL) courses generally encourage active learning, develop critical thinking, and promote teamwork. While numerous PBL cases exist in the field of medicine, there is a notable lack of such cases in STEM fields. We teach Communication Networks for master's students incorporating PBL concepts.

The course brings together first-semester international and local students from various study programs, each with different levels of knowledge, soft skills, and cultural backgrounds. This diversity creates an exciting environment for applying PBL, fostering collaboration between students and teachers to enhance understanding. We integrate four PBL exercises with lecture content.

As shown in Table 1, PBL1 and PBL3 are introduced before the corresponding lecture topics are covered. This approach helps students become familiar with the topic and fosters curiosity to learn more during the lecture. For instance, PBL1 encourages students to explore key performance indicators (KPIs) for evaluating communication network performance, using a real-world example of Digital Subscriber Line (DSL) networks in student hostels. With diverse academic backgrounds, students propose varied solutions, and the subsequent lecture refines their understanding by introducing the right KPIs along with additional metrics for other network types, such as platooning and wireless networks. In contrast, PBL2 and PBL4 are designed for

Week	Lecture Contents Related to PBL	PBL Exercise Contents
1st - 2nd	Introduction to Key-Performance-Indicators (KPI)	PBL 1 - Performance Metrics
3rd - 4th	Blocking Probability	PBL 2 - Reliable Communications over Long Distance
5th - 6th	Ethernet: Carrier Sense Multiple Access / Collision Detection (CSMA/CD); WLAN: Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA)	PBL 3 - Reliable Media Access Control (MAC)
7th - 8th	Transport Layer Transmission Control Protocol (TCP) and User Datagram Protocol (UDP)	PBL 4 - Reliable End-to-End Data Transmission
9th - 14th	---	PBL 5 - Selected Topics in Communication Networks

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Tab. 1: Interaction with related lecture contents and PBL contents

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Fig. 1: Poster presentation of PBL5 - receiving feedback from experts and peers

deeper discussions after students have acquired fundamental concepts through lectures. For example, the blocking probability lecture introduces how to use theoretical models to estimate the behavior of a communication network. Later, PBL2 focuses on discovering a solution to mathematically prove the link quality based on channel errors.

Once the students complete four PBLs, we introduce a special PBL case, called "Selected Topics in Communication Networks", which explores emerging topics in the field during the final six weeks of the semester. We continuously seek new ideas to ensure this PBL remains relevant to current technological advancements. In this paper, we share our experiences in designing these PBLs, detailing our revision process, engagement strategies, and student feedback.

2. PBL5 – SELECTED TOPICS IN COMMUNICATION NETWORKS

In the winter semester 2024/25, 48 students participated in our last PBL focused on reliable communication for smart factories, space applications, UAV mobility, and indoor localization.

Designing these PBLs is challenging, as it requires incorporating current research trends while ensuring alignment with the lecture content. The learning objective is researched and presented by a team of three students, based on a research paper selected by the team. They take this PBL seriously as 75% of the exam grade is determined based on it, followed by a poster presentation session for all students (see Figure 1).

In the next section, we will explain in detail how we design and implement new PBLs on Selected Topics of Communication Networks in this semester.

3. REALIZATION OF PBL5

Four key topics were considered for PBL5. The selection of these topics prioritizes trending topics in communication networks while also aligning with tutors' areas of expertise or ongoing PhD research areas. Additionally, we evaluated how well students could apply the concepts learned during the lecture to these four PBL cases:

1. **Smart Factory:** Random MAC protocols such as CSMA/CD and CSMA/CA were covered in the lecture, and students became familiar with enabling reliability in multi-user media access during PBL3. This topic encourages further exploration of how to achieve reliability and examines existing research solutions.

2. **Mapping the Invisible (Localization):** As students are familiar with different wireless technologies like WiFi, Bluetooth, Ultrawideband, ultrasound, cellular etc., this topic aims to inform students on how these technologies can be used by devices for positioning in places where GPS fails. The techniques to discover positions are not taught during the lectures and this PBL focuses on applying already learned concepts for a completely different application.

3. **Reliable Communication for Urban Air Mobility:** Students learned about routing protocols used on the internet, as well as cellular and WLAN communication technologies. This topic deepens their understanding of using wireless technologies over multiple hops.

4. **Space Communications for Moon Missions:** This topic was particularly challenging as space communication differs significantly from the terrestrial networks studied in the lecture. It encourages students to explore innovative solutions for space-related challenges, such as handling intermittent connections using their knowledge of the TCP/IP protocol stack.

We usually develop new PBL topics in collaboration with the ZLL. The goal is to obtain input from pedagogy experts to ensure that the exercise aligns with best practices in teaching and learning to foster student engagement and deep understanding. The ZLL remains up to date on the latest educational trends and technologies and is expected to significantly contribute to introducing innovative ways to make the PBL exercise more impactful.

Here, we illustrate the procedure using the PBL case "Smart Factory", developed based on our PBL3 named as "Reliable Medium Access Control (MAC) for Industrial Internet of Things (IIoT)". The goal of PBL3 is for students to have a deeper understanding of different MAC protocols.

Our collaboration with the ZLL began by submitting the initial version of this PBL exercise for their review and feedback, focusing on the best practices in this teaching method. Their

Original Version

PBL3 - Reliable Medium Access Control (MAC) for Industrial Internet of Things (IIoT)

Norman wonders why he cannot use Wi-Fi for his newly started company to enable monitoring and controlling of an additive manufacturing process for aerospace industry.

In IIoT applications, deterministic communication is critical to meet the stringent requirements in terms of latency, and reliability in real-time systems. IIoT systems often operate in environments where precise timing and coordination are

essential, such as in manufacturing, autonomous robotics, and industrial automation. For instance, real-time control systems used in manufacturing lines rely on synchronized data exchange to ensure proper sequencing and coordination of processes. Delays or interference-disrupted communication leads to inefficiencies, product defects, or even safety hazards.

Popular MAC protocols like Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA), as used in Wireless LANs (e.g., Wi-Fi), provide random backoff delays to avoid collisions on shared channels. This technique is inherently non-deterministic, as it introduces variable delays and cannot guarantee a bounded transmission time. This randomness is unsuitable for IIoT applications, where deterministic timing is required to maintain the regular intervals and strict coordination across devices.

Thus, Norman asks for your help with selecting the most reliable MAC protocol. He is also not sure how to evaluate whether a given MAC is suitable for his scenario and a comprehensive comparison including several KPIs is appreciated. Since his factory plant is not completely shielded against radio waves, external interference may have an impact on the performance of the wireless IIoT system.

Improved Version

PBL3 - Reliable Medium Access Control (MAC) for Industrial Internet of Things (IIoT)

You are trying to establish a company specialized on additive manufacturing for aerospace industry.
To be competitive on the market with high-quality products, the manufacturing process must be monitored continuously throughout the factory plant. For this purpose, multiple sensors and actuators are distributed across the plant.Sensor data like temperature and pressure readings must be delivered to the control unit in timely manner to adjust the manufacturing process accordingly using actuation commands.

Since wiring is not feasible due to the complexity of the plant, you opted for a Wi-Fi network with a single access point for the communication between sensors, actuators and the control unit.

First product batches turned out to contain defects. After careful examination of the equipment, it seems that actuators are not executing commands from the control unit within the required latency bound and some sensor data is also missing. The plant is located in an industrial area with several other factories nearby.

Fig. 2: Original and improved version of PBL3

insights significantly helped us improve the exercise description, making it more precise and aligned with the core objectives of PBL in general. The PBL3 exercise description before and after their input is shown in Figure 2.

Furthermore, before arriving at the improved version of the exercise, we engaged with the ZLL to take the PBL exercise as a workshop among tutors. Each step was facilitated by a different tutor. The other tutors had the opportunity to get to know the students' perspective. This hands-on experience helped us to gain more insight on how the exercise should be facilitated from the tutors' viewpoint in accordance with the ZLL's approach and how students would start working with our case.

Key takeaways:

1. **Lack of curiosity in the problem description:** One of the main elements in PBL is igniting student curiosity. Reflecting on the workshop, we recognized this was lacking. This is because the problems presented were overly structured, leaving little to no room for creative and independent thinking (refer Figure 2 - original version).

2. **Too Lengthy:** The problem description was too extended, which can make it difficult for students to take in key concepts and can also be demotivating.

3. **Problem over-disclosure:** Some terms and statements from the problem description may have revealed too much information regarding the potential solution, thereby limiting the curiosity and inquisitive aspect of the PBL.

During the workshop, we also rotated through different roles as moderators, minute-takers, tutors, and students. Another general take away from the workshop was that tutors should always observe the PBL session from the side without dominating discussions or idea development. They must stand back, be patient and intervene only when necessary to keep the session on track, because every intervention makes student teams feel less comfortable and less confident to make it on their own. Sometimes to observe for another 30 seconds makes a huge difference, because students find their mistake or the next step by themselves.

After we realized these issues on our own, we revised PBL3 as shown in Figure 2 - improved version, without revealing all the hints that we would have otherwise given to the students.

4. PRACTICE OF PBL5 "SMART FACTORY" WITH 7 STEPS

As PBL relies on the active participation of students for effective learning, a student engagement strategy is a vital factor to consider. True engagement in learning means students do not just memorize things. Rather, they analyze information, synthesize different perspectives, and apply their knowledge to achieve meaningful outcomes.

In this section, we discuss our experience based on the PBL topic **"Smart Factory"**, incorporating the key takeaways from our workshop with ZLL, as shown in Figure 3.

Before commencing the PBL session, it is crucial to have the right setup. Students are assigned to groups of about 12 students, sitting down facing each other. The group selects a

Smart Factory

In PBL 3 you have worked out the slotted medium access as a solution for reliable and timely delivery of sensor data in the smart factory context.

Trying to enable Timeslotted Channel Hopping (TSCH) on your Wi-Fi-based devices, you found out TSCH does not work under the standard TCP/IP stack due to the limited Maximum Transmission Unit (MTU) of 127 bytes.

Your investigation led you to the IPv6 over the TSCH mode of IEEE 802.15.4e (6TiSCH) protocol stack, which supports IP-based communication over TSCH through an adaptation layer. However, you also found out that the 6TiSCH stack is not yet widely supported by the industry and has two configuration-sensitive components: the routing protocol RPL and the scheduling function (SF).

Since there are many flavors of RPL and different SFs, you must investigate which of those are suitable to fulfill Quality-of-Service requirements, such as low latency, high reliability, and low energy consumption.

Stakeholders additionally require you to provide a variety of results, including experimental and analytical evaluations, as well as simulations to support your arguments.

Fig. 3: Problem description of PBL5 (Smart Factory)

moderator who oversees keeping track of time and coordinating the PBL session. A minute taker is also selected from the group, who keeps track of the discussion and points raised during the session. Students wear name tags to facilitate easy identification by their peers in the group.

Once the PBL case has been provided, students are expected to walk through it, using the seven-step approach (Weber, 2005) to the problem.

Step 1 – Resolve Unclear Terms: The group identifies terms or concepts that are vague, or open to interpretation. Sharing what they know for a more interactive learning experience.
New terms: TSCH, IPv6 Adaptation Layer, 6TiSCH protocol stack

Step 2 – Identify Problems and Knowledge Gaps: Students analyze and break down the problem to identify the key topics.
Major problems identified: Application of TSCH to the existing network infrastructure, configuration of the scheduling function and routing protocol (RPL).

Step 3 – Hypotheses and Solutions: In a brainstorming students find preliminary answers or explanations.
The students largely suggested using the 6TiSCH stack with optimized configuration for the scheduling function and RPL to address delay- and reliability-sensitive Quality of Service (QoS) requirements of an Industry 4.0 application.

Step 4 – Sort and Rate: Hypotheses and solutions are structured and prioritized, so students can focus on the most feasible or effective approach or solution.
Key ideas around RPL and TSCH were selected.

Step 5 – Define the Learning Targets: With these key ideas and some guidance from tutors, students clearly define what their learning targets are.
Final 4 learning targets: the 6TiSCH stack itself and the respective KPIs, namely low latency, low energy consumption and high reliability.

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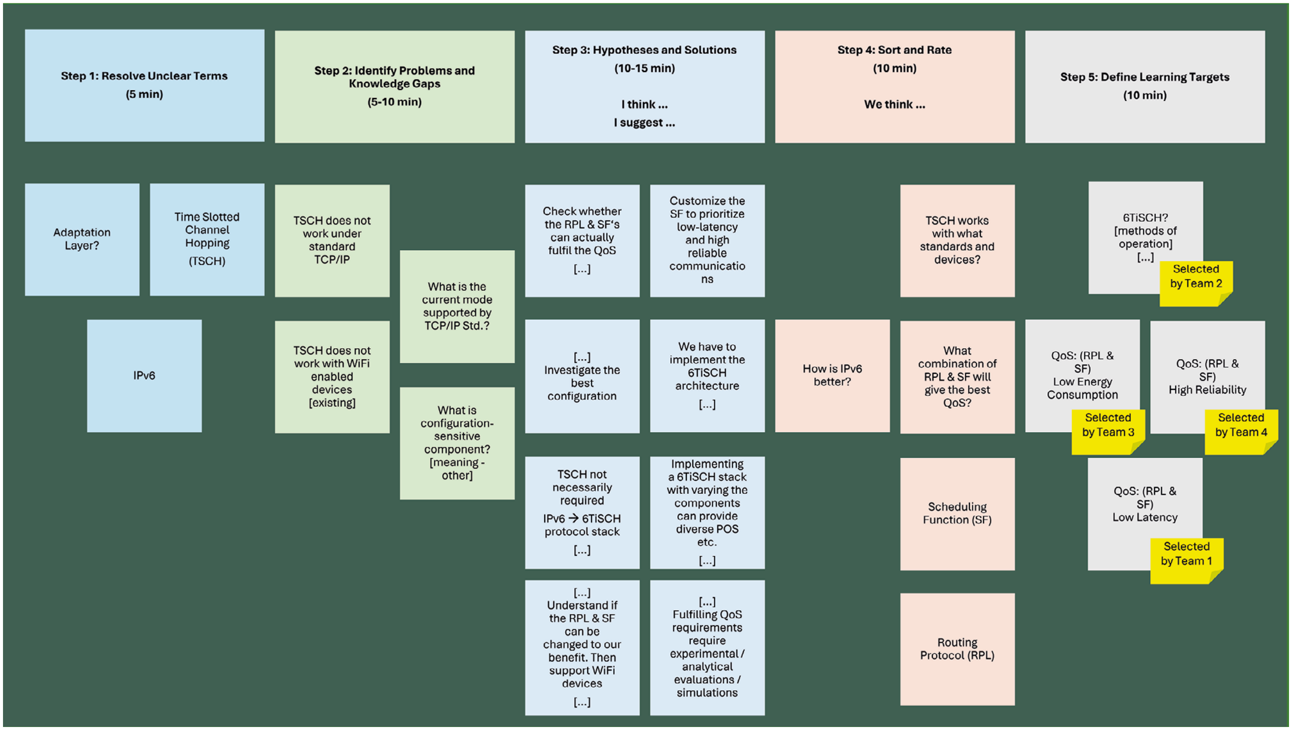

Fig. 4: Example Walk Through of one Student Group from PBL5 (Smart Factory)

After choosing a topic each, the teams can move on to Step 6 and 7 of the PBL.

Step 6 – Individual research: In this self-study phase, students gather additional knowledge from various sources, including course materials, books, research papers, and online resources, based on their learning targets. Each team selects a research paper from a reputable journal or conference, ensuring it aligns with their assigned topic.

Students must justify their selection to their tutor based on criteria such as context clarity, result analysis quality, and citation count relative to the paper's age.

For the **Smart Factory PBL,** students found:

- A reference on the 6TiSCH protocol stack and performance evaluation – (Vilajosana et al., 2019).
- A low-latency scheduling function for delay-sensitive applications – (Pradhan et al., 2022).
- An optimization method for low-power devices, improving the join process and idle listening in 6TiSCH networks – (Van Leemput et al., 2024).
- An emergency-aware scheme enabling reliable data delivery via cell hijacking at the TSCH layer – (Farag et al., 2021).

Step 7 – Discussion and Synthesis: Generally, the goal in this step is for students to discuss their findings based on step 6. Through these discussions, students aim to collaboratively arrive at a solution to the problem. However, for PBL5, students present their findings in the form of a poster based on the paper they select in Step 6. The poster must be designed to conform with good scientific practice (Deutsche Forschungsgemeinschaft, 2025). Students then present their findings during a public poster session, normally organised at the end of the semester, to the faculties, students, and other guests as can be seen in Figure 1.

5. STUDENTS FEEDBACK

During the final poster session, we collected student feedback physically, as illustrated in Figure 5. Each cross represents a student's response, and the colors correspond to our four topic areas: Black – "Smart Factory," Red – "Mapping the Invisible (Localization)," Blue – "Reliable Communication for Urban Air Mobility," and Green – "Space Communications for Moon Missions."

The assessment was divided into two categories:

1. **Group Work Evaluation:**
   · Communication within the team
   · Time Management
   · Group Organisation
2. **Individual Assessment:**
   · Scientific Contents: The perceived difficulty of understanding the topic.
   · Workload: The amount of effort required from everyone.

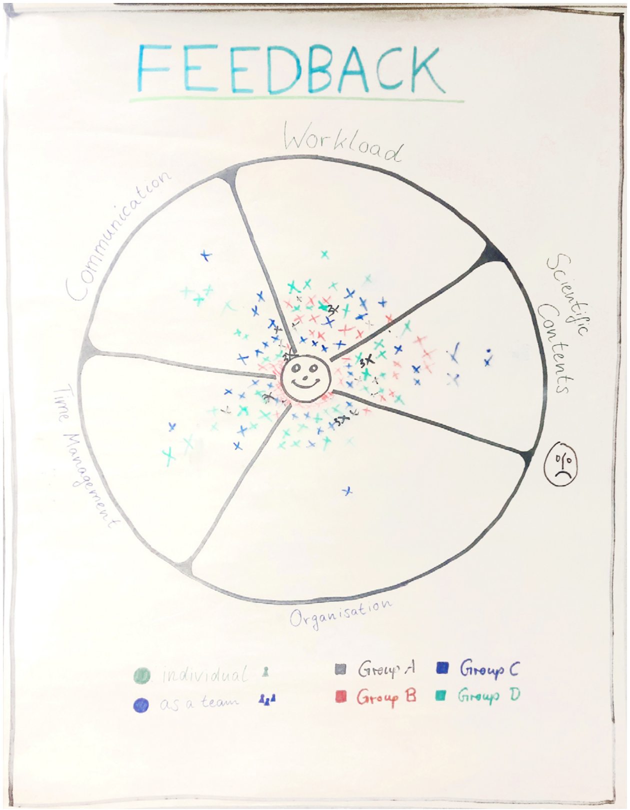

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Fig. 5: Feedback for PBL5 from 48 students from winter semester 2024/25

The smiley face at the center indicates a positive evaluation, while the sad face represents areas with lower ratings. Most feedback is clustered around the center, suggesting generally positive experiences, with some variations for the **Scientific Contents.**

6. LESSONS LEARNED AND OUTLOOK

Our final, exam-oriented PBL, spanning six weeks, provides several benefits for students.

1. **Literature Review:** Students are required to find and justify a reference paper for their poster, evaluating criteria such as relevance, citations, and publication date. This practical approach enhances their literature review skills and deepens their understanding of the topic.

2. **Poster Preparation:** Creating the poster helps students learn template usage, content organization, and scientific referencing. Space limitations encourage them to present only the most relevant findings while maintaining a clear, convincing narrative.

3. **Teamwork & Soft Skills:** Collaborative research and poster development improve teamwork. Students with strong collaboration skills complete tasks more efficiently, while others gain experience in group work. Differences in motivation create peer-learning opportunities, benefiting both less-engaged and advanced students.

4. **Time Management:** Strict deadlines for paper selection and final poster submission mirror real-world working conditions, helping students develop time-management skills.

Despite these benefits, we as tutors faced several challenges.

- **Consultation & Engagement Issues:** Some students miss consultation sessions, leading to errors and knowledge gaps. Unmotivated teams often lack a driving force, reducing overall effort and affecting the final output.

- **Literature Review Challenges:** Since PBL5 serves as an exam basis, tutors must ensure suitable papers are available. This process is time-consuming, and less motivated groups often submit papers without justification, increasing the tutors' workload.

- **Defining Learning Targets:** Clear, well-structured learning objectives in PBL Step 5 are essential for high-quality posters and presentations. Poorly defined targets can disadvantage teams, requiring tutors to refine them despite PBL's principle of minimal intervention.

- **Group Distribution Issues:** Students select topics on a first-come, first-served basis, often leading to uneven group sizes and dissatisfaction. Some students prioritize working with friends, adding complexity to the process.

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