Challenge-Based Learning for Developing Data Integration Solutions in Remote Patient Monitoring Systems

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***Abstract*—This paper presents the results of the RAID-BIO educational innovation project, a Challenge-Based Learning (CBL) experience implemented in a Biomedical Engineering course. The project engages students with real-world healthcare challenges through two types of nano-challenges: one provides extensive supporting materials to guide students, while the other requires higher levels of independent investigation and problem-solving. Project evaluation includes a comparison of academic performance with traditional laboratory exercises, as well as a student satisfaction survey. At the time of writing, the CBL experience is ongoing, and a full assessment of its impact will be conducted in future work.**

***Index Terms*—Challenge-Based Learning, Education, Biomedical Engineering.**

I. Introduction

In recent years, hospital biometric data management platforms have evolved significantly through the integration of sensors and communication networks. The increasing use of Internet of Things (IoT) devices in healthcare has automated tasks traditionally performed manually, such as patient data collection, storage, and visualization.

Traditional laboratory exercises in communication networks for Biomedical Engineering students often focus on purely technical challenges, lacking real-world or societal context. The RAID-BIO educational innovation project addresses this limitation by engaging these students in a socially relevant challenge: designing and implementing a remote monitoring system. Leveraging a Challenge-Based Learning (CBL) framework, the project promotes learning by doing and encourages students to take ownership of their education through a series of smaller and manageable tasks, known nano-challenges, which collectively contribute to solving the overarching problem. This approach supports the development of technical competencies and fosters critical thinking, collaboration, and student motivation.

The main objective of this work is to present the design of a Biomedical Engineering course that incorporates CBL through two types of nano-challenges: one more guided and straightforward, and another more open-ended and complex. The study aims to explore whether the provision of supporting materials can calibrate the difficulty of the challenges and evaluate the potential impact of CBL activities on students' academic performance compared with traditional laboratory exercises. Although the CBL experience is still ongoing, presenting the course structure and defined nano-challenges, along with the associated student survey, provides a practical reference for designing and implementing similar challenge-based learning experiences in engineering education.

The remainder of this paper is organized as follows. Section II reviews related work on CBL in engineering education. Section III describes the RAID-BIO project. Section IV presents the course design. Section V outlines the implementation of CBL, including the definition of the nano-challenges and the design of a student satisfaction survey to collect feedback on the learning experience. Section VI discusses the ongoing status of the CBL experience, and Section VII concludes the paper.

II. Related Work and Main Contributions

A. Related Work

The literature reports several studies describing CBL experiences in engineering education [1], some of which focus on how a global challenge can be split into smaller units of shorter duration, referred to as mini- or nano-challenges [2], [3]. Regarding the definition of these mini- and nano-challenges, Conde *et al*. [4], [5] provide templates that we extended in our research by including a supplementary information field, which allows instructors to adjust the difficulty level of each challenge. In the field of Biomedical Engineering, several studies also describe CBL implementations. For example, Membrillo-Hernández et al. [6] focused on the pedagogical training that teachers should receive, as well as the role digital tools, such as Zoom or Canvas, play in helping students acquire their competencies. Other research by Gumuscu et al. [7] describes how they designed a course within a Biomedical Engineering degree program that incorporates CBL throughout the entire subject. In our research, we designed our course by combining traditional methodologies with CBL activities in order to examine how students value both pedagogical approaches. Unlike Martin *et al.* [8], who compared traditional and CBL methods across different groups of students, our study also includes a hybrid approach within the same course, where students experience both methods. This allows us to assess not only the differences between groups, but also how the same students respond to different teaching methods.

B. Main Contributions

Based on the review of related work presented above, the contributions of this research are as follows:

- We designed a Biomedical Engineering course that combines traditional activities with challenge-based nano-projects.
- We propose a new template for defining nano-challenges that includes *Supplementary Information*. Our hypothesis is that this addition can help to level the difficulty of the challenges. We also propose a survey to validate this hypothesis.
- We implemented our course design proposal, but it is still ongoing at the date of this publication.

III. RAID-BIO Project Description

The RAID-BIO project proposes a Challenge-Based Learning (CBL) experience in which students build a Complete Biometric Monitoring System for a hospital. Developing this system requires students to acquire competencies in IP networking, IoT protocols, Biomedical Engineering, and data management, while understanding how the different subsystems combine to form a unified healthcare monitoring platform.

Through a combination of traditional laboratory assignments and nano-challenges, students progressively develop and implement the Complete Biometric Monitoring System. The main components of the system and their associated activities are:

- **Biometric Streaming Terminal** (*traditional laboratory assignment*): Students learn how IoT biometric devices generate and publish data using standard communication protocols. This activity introduces fundamental concepts in sensor interfacing and data acquisition.
- **Biometric Data Visualization** (*traditional laboratory assignment*): Students develop tools for collecting, managing, and visualizing biometric data.
- **Network Configuration** (*traditional laboratory assignment*): Students design the hospital network architecture, including IP addressing and device connectivity, and deploy it using a virtual network environment. This component ensures that students understand network design and the deployment of connected devices.
- **Biometric Receiver and Alert System** (*nano-challenge*): This is one of the two nano-challenges defined in the course. Students implement a module to process incoming biometric data and generate alerts for out-of-range measurements. This challenge is guided, providing supporting materials to help students work through the task and ensure its successful completion, as described in Section V.
- **Complete Biometric Monitoring System** (*nano-challenge*): This is the second nano-challenge defined in the course. Students integrate all previously developed components into a Complete Biometric Monitoring System. Unlike the previous nano-challenge, this task is less guided and provides minimal supporting information, placing greater emphasis on independent investigation, problem-solving, and collaboration. Further details are provided in Section V.

IV. Course Design

Table I presents the course design, which aims to develop competencies in communication networks within the context of a Biomedical Engineering degree. The course integrates traditional laboratory activities with newly introduced CBL experiences, allowing students to engage with both strategies and provide feedback on their perceived strengths and weaknesses for each teaching approach.

In the first part of the course (W1–W8), students receive a greater amount of theoretical content, since they first need to acquire the fundamental concepts related to the technologies they will use throughout the course. However, the course introduces practical work from the very beginning: as soon as students gain the essential theoretical background, the program incorporates laboratory activities. Indeed, by Week 2 they already begin applying the concepts introduced in the lectures through hands-on lab exercises focused on developing the Biometric Streaming Terminal. Throughout this first stage of the course, all teaching activities remain organized around traditional teaching methods, combining theory-based lectures with guided laboratory work. The transition to the second stage of the course, starting after the midterm exam in Week 9, marks the point at which Challenge-Based Learning activities are introduced.

From Week 10 to Week 14, students work on two nano-challenges. The first focuses on the design of a Biometric Receiver and Alert System and is implemented with a more guided approach, providing students with additional information and resources to help them understand and address the challenge. The second nano-challenge focuses on the integration of all previous developments into a complete Biometric Monitoring System and is designed as a more open-ended task, with limited additional information to emphasize student-led investigation and active tutorial support. This second nano-challenge represents a significant portion of the overall assessment (25%). At the end of the second part of the course, a final exam is scheduled in Week 17, contributing 10% to the overall grade. This exam complements the assessment of the nano-challenges and specifically evaluates whether students have successfully acquired the theoretical competencies targeted during this stage of the course.

This course design carefully interleaves theory and practice by combining traditional lectures, guided laboratory exercises, and challenge-based activities. Below, we provide a more detailed description of how we have implemented the CBL learning experience within the course.

TABLE I: Course design

(a) Weeks W1–W7

	W1	W2	W3	W4	W5	W6	W7
Activity	Live Lecture and Q&A	Live Lecture and Q&A		Live Lecture and Q&A		Live Lecture and Q&A	Live Lecture and Q&A
Assessment	n/a	n/a		n/a		n/a	n/a
Activity		Lab. Assignment 1: Biometric Streaming Terminal	Lab. Assignment 1: Biometric Streaming Terminal		Lab. Assignment 2: Biometric Data Visualization		
Assessment		5%			5%		

(b) Weeks W8–W14

	W8	W9	W10	W11	W12	W13	W14
Activity			CBL theoretical overview		Live Lecture and Q&A	Live Lecture and Q&A	
Assessment			n/a		n/a	n/a	
Activity	Lab. Assignment 3: Network Configuration		Nano-challenge 1: Biometric Receiver and Alert System	Nano-challenge 1: Biometric Receiver and Alert System			Nano-challenge 2: Complete Biometric Monitoring System
Assessment	5%		5%				25%
Activity		MidTerm Exam					
Assessment		45%					

(c) Week W17

	W17
Activity	MidTerm Exam
Assessment	10%

V. Implementation of CBL

We have developed a template (Table II) that can be used to define the challenges. The design of this template is based on examples and guidelines from the literature. More specifically, we were inspired by the challenge templates provided by Conde *et al.* [4], [5], which include the following fields: *Title*, *Essential Question*, *Description*, *Goals*, and *Evaluation*.

In addition, we incorporated two extra fields based on the recommendations of the CBL guide by Digital Promise [2]. This guide suggests supporting students with *Guiding Questions* and *Guiding Activities* during the investigation phase. Finally, we added a *Supporting Documentation* field based on the approach proposed by Shank *et al.* [9], where students begin with a set of materials that they use during the investigation phase to develop the challenge.

In the following subsection, we describe each of these template fields and illustrate their application in the specific nano-challenges defined in the course.

TABLE II: Mini/Nano challenge template

Title	Provide a title for the challenge
Essential Question	Formulate the essential question that the challenge is designed to address
Description	Provide a detailed description of the challenge
Goal/s	Specify the goals of the challenge
Guiding Questions	List one or more questions to structure the learning experience
Guiding Activities	List one or more activities that help answer the guiding questions
Supporting Documentation	List or describe the resources, references, or documentation available
Evaluation	Describe how the learning experience will be evaluated

A. Description of Nano-challenges

Tables III and IV show the completed templates for the Biometric Streaming Terminal and the Complete Biometric Monitoring System nano-challenges, respectively. These tables present a simplified version of the material actually provided to students, illustrating how the fields of the template are applied in each specific case. For example, in the complete statement of the nano-challenges, we not only formulate the *Essential Question* but also provide supporting materials, such as copyright-cleared photos and AI-generated visuals, to provide context and motivation for the challenge. For example, one of the statistics provided to students comes from the University of Michigan, which reports a 59% reduction in hospital admissions due to remote patient monitoring [10].

We have defined the *Description* and planned learning *Goals* of the challenges in a way that extends beyond the acquisition of technical competencies. Their formulation helps students understand the relevance and practical usefulness of the technology they are learning in relation to solving the challenge. Although the content is similar to what is typically found in laboratory assignments, it is presented to emphasize the importance of addressing the challenges.

The overall difficulty of the challenges is determined by three specific fields of the template: *Guiding Questions*, *Guiding Activities*, and *Supporting Documentation*. In both nano-challenges, the *Guiding Questions* and *Guiding Activities*

TABLE III: Nano-challenge 1: Biometric Receiver and Alert System

Title	Biometric Receiver and Alert System
Essential Question	How can biometric data be monitored and interpreted in real time to detect changes in patients' vital signs?
Description	Students design a system capable of receiving and analyzing patients' vital signs in real time, identifying anomalies, and generating automatic alerts to support clinical decision-making in remote monitoring contexts.
Goal/s	• Understand the principles of real-time biometric data processing. • Design mechanisms for detecting anomalous physiological values. • Develop an alerting strategy that supports patient safety.
Guiding Questions	• What data are essential to assess patient status? • How can anomalies in vital signs be identified? • What information should an alert contain to be useful for clinicians?
Guiding Activities	• Interpret sample biometric datasets. • Define thresholds and rules for anomaly detection. • Prototype an alert-generation system.
Supporting Documentation	• Reference materials on remote monitoring and vital-sign interpretation.
Evaluation	• Clarity and coherence of the proposed monitoring and alerting strategy. • Correct interpretation of biometric data and detection of critical events. • Quality and completeness of the challenge deliverables.

TABLE IV: Nano-challenge 2: Complete Biometric Monitoring System

Title	Complete Biometric Monitoring System
Essential Question	How can we implement a comprehensive remote monitoring system that enables a hospital to improve patient care?
Description	Integration of all course-developed subsystems to build a remote monitoring system prototype for enhanced patient care and early health-issue detection.
Goal/s	The overall objective of this challenge is to create a prototype of the remote monitoring system. To achieve this, you must: • use the Biometric Streaming Terminal developed in *Lab. Assignment 1*; • use the Biometric Data visualization tool analyzed in *Lab. Assignment 2*; • apply the network configuration as in *Lab. Assignment 3*; • use Biometric Receiver and Alert System developed in *Nano-challenge 1*.
Guiding Questions	• What role does the Biometric Streaming Terminal play in communicating with the Biometric Receiver? • Why is proper IP and routing configuration essential to ensure communication between all devices and services? • What information is transmitted to the Biometric Receiver, and how can its correct delivery be verified? • Why is real-time data visualization important, and how does anomaly detection help anticipate potential health issues?
Guiding Activities	• Deploy the lab scenario. • Configure the network to ensure connectivity between devices. • Launch the Biometric Receiver, and the visualization tool. • Generate and stream biometric metrics from the Biometric Streaming Terminal. • Visualize real-time data and monitor for anomalies. • Run the subscriber/anomaly-detection program to trigger alerts.
Supporting Documentation	• No additional documentation is provided for this challenge.
Evaluation	• Correct functioning of the complete biometric monitoring system. • Quality and completeness of the challenge deliverables.

follow the same approach, helping students structure their investigation and work toward addressing the *Essential Question*. However, the *Supporting Documentation* differs between the two challenges and serves to calibrate difficulty. In our CBL implementation, we have been particularly interested in examining how the difficulty can be adjusted through this field.

The investigation phase can be more or less structured, depending on the extent and specificity of the material provided to the students. In the nano-challenge focused on the Biometric Streaming Terminal, the *Supporting Documentation* is extensive and designed to allow students to complete the *Guiding Activities* without significant difficulty. In contrast, in the nano-challenge focused on the Complete Biometric Monitoring System, no supporting information is provided, requiring a higher level of independent investigation and problem-solving to complete the activities. At the end of the CBL experience, students evaluate the *Supporting Documentation* for the Biometric Streaming Terminal nano-challenge and indicate whether the provided information was useful. For the Complete Biometric Monitoring System nano-challenge, they are asked whether they would have preferred additional supporting information to complete the *Guiding Activities*.

Finally, the challenge statement concludes with an evaluation section that specifies the outcomes and performance expectations communicated to the students.

B. Evaluation of CBL methodology

The CBL implementation is evaluated from two complementary perspectives. First, we compare the academic performance of students in the nano-challenges with their per-

TABLE V: Survey Questions Formulated to the Students

Survey Question	Scale
Q1. Do you prefer CBL-based activities over traditional laboratory assignments?	Yes/No
Q2. The introduction of the challenge, including illustrative images and statistical data, increased my motivation to solve it.	Strongly Disagree – Strongly Agree
Q3. The supplementary information provided was useful for completing Nano-challenge 1.	Not at all – Completely
Q4. Would you have preferred additional supporting information to complete Nano-challenge 2?	Yes/No
Q5. In your opinion, to what extent does the difficulty of the challenges depend on the supplementary information provided?	Very little – Very much

formance in traditional laboratory assignments. Specifically, the grades obtained by students in the nano-challenges during the 2025-26 academic year are compared with the grades obtained in the same activities when they were carried out as traditional laboratory practices in the 2024-25 academic year. In addition, we analyze whether the change in teaching methodology within the current course introduces any imbalance by comparing the grades for laboratory practices and nano-challenges of students in the 2025–26 academic year.

Second, student feedback is collected through satisfaction surveys. Table V contains the questions formulated for the students. Students are asked whether they preferred the CBL-based activities over traditional laboratory assignments (Q1), and whether they felt more motivated to solve the challenges than the laboratory exercises (Q2). These questions aim to assess whether the CBL-based methodology increases students' motivation to engage with the challenges, in part due to the inclusion of illustrative images and statistical data that provide context and highlight the relevance of the task. The survey also includes questions regarding the usefulness of supplementary information, asking whether the material provided was helpful in completing Nano-challenge 1 (Q3), or whether additional information would have been desirable for Nano-challenge 2 (Q4). Finally, students are asked to indicate their perception of how the difficulty of the challenges depends on the supplementary information provided (Q5).

VI. Results

At the time of writing this version of the paper, the CBL experience is still ongoing. Consequently, the data required to fully evaluate the effectiveness of the proposed methodology—including academic performance comparisons and student satisfaction surveys—is not yet available. The results that are presented in this study therefore focus on the design and implementation of the nano-challenges, with the evaluation of their impact being planned for future work.

VII. Conclusions

As part of the RAID-BIO educational innovation project, we conducted a Challenge-Based Learning (CBL) experience in a Biomedical Engineering course, aiming to enhance technical competencies, critical thinking, collaboration, and student motivation by engaging learners with real-world, socially relevant challenges. Two types of nano-challenges were implemented: the Biometric Streaming Terminal, which offers extensive supporting materials to guide students through the tasks, and the Complete Biometric Monitoring System, designed to require a higher level of independent investigation and problem-solving.

The evaluation of the experience includes both academic performance comparisons with traditional laboratory exercises and student satisfaction surveys. However, at the time of writing, the CBL experience is still ongoing. A full assessment of its impact on learning outcomes and motivation will be conducted in future work. Nonetheless, this paper demonstrates a feasible approach to integrating CBL into a Biomedical Engineering course. We successfully defined the course structure to include CBL activities, developed the specific nano-challenges for this experience, and designed a student satisfaction survey to gather feedback.

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