Title: Case-study of teaching technological literacy for laboratory technological professions in the framework of computational thinking

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Abstract

Technological literacy (TL) is a central theme in healthcare and laboratory professional education. The rapid speed of technological development in the healthcare sector, clinical and laboratory practice calls for new knowledge, skills and attitudes in future professionals and therefore for new approaches in teaching. Here we describe a teaching approach based on computational thinking (CT) and aimed at increasing the TL of biomedical laboratory science (BLS) students. We discuss the background for why we use CT as framework, the intended learning outcomes and how these link to the needs in the students' future practice. Furthermore, in an international network of teachers and researchers in the BLS, Chemical and Biotechnical Science and radiography education programs, we carried out a systematic observation study of parts of the teaching and use the reflection notes from the observer group to discuss how the intended TL competencies play out in the teaching sessions and the students´ activities in these. We discuss how the teaching approaches support, or not, the development of the students´ TL. This study is part of an Erasmus+ network aimed at developing novel teaching approaches to support students´ technological literacy.

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Introduction

Digital technologies, such as advanced computing, big data, AI, virtual reality, and robotics, are becoming increasingly important in the effort to improve prevention, diagnosis, treatment and monitoring of health issues (European Commission, 2019; WHO, 2021). This growing reliance on digital solutions is particularly evident in health professions with an application-oriented technology focus such as biomedical laboratory science (BLS), where technology is not just a tool but an integral part of the daily practices (Danmarks Evalueringsinstitut, 2018). Due to this shift, it is crucial to understand how educational programs can prepare future professionals to navigate, evaluate, and apply these technologies effectively. To meet this demand, didactical strategies must engage students in problem-solving and critical reflection on technology in practice. In recognition of this, the present study explores how educational programs can support students in developing the necessary competencies through an active learning approach that emphasizes critical interaction with complex technologies. Employing a case study design, this leads to the following research question:

How can teaching practices support technological literacy by engaging students in problem-solving processes inspired by computational thinking, during practical learning activities?

This article contributes to the field of professional education by proposing computational thinking as a theoretical lens to inform didactical strategies for fostering technological literacy among students preparing for practice in technology-rich professions.

BLS in a digitalized healthcare sector

We begin by addressing the demands placed on BLS within an increasingly digitalized healthcare sector. BLS constitute a large part of the staff in diagnostic laboratories and clinical physiology departments of hospitals, playing a key role in analyzing patient samples and conducting patient examinations to ensure accurate diagnoses and effective treatments. Production of diagnostic data integrates the fields of biology, chemistry and medicine as well as technology, digitization and automation. With most laboratory workflows now digitized, BLS professionals must have a deep understanding of the impact and significance technology has within their profession. This aligns with the core competence guidelines from The International Federation of Biomedical Laboratory Science (2022), which highlights the importance of continuously updating *"technical knowledge and skills"* to ensure high-quality patient diagnostics. To meet these recommendations, BLS education programs need to prepare healthcare professionals to navigate and utilize digital advancements (Adler et al., 2023; Jensen et al., 2024). This requires a broad set of competencies, including communication skills (Stollenwerk et al., 2022), operating and maintaining analytical equipment (European Commission, 2024), technical proficiency (Liikanen, 2019) and digital proficiency (Jensen et al., 2024).

Central to this, is fostering technological literacy (TL), *i.e.,* the ability to understand technology, use it effectively and critically assess its risks and benefits to make informed decisions (Shachak et al., 2024). A key element of TL is maintaining an optimistic mindset, as emphasized by ITEEA (2022), which involves recognizing opportunities in challenges and persistently seeking solutions through experimentation and adaptation. Digital competencies form an important subset of TL, focusing on the effective use of digital tools, platforms, and resources, including skills such as digital communication, information management, and ethical technology use (Yeşilyurt & Vezne, 2023). In the context of developing these digital competencies, the Digital Competence Framework for Citizens, DigComp 2.2 (European Commission, 2022) offers a structured approach to identify knowledge, skills and attitudes within this, which is, in principle universally applicable and that we also find to be a good fit for the BLS profession. The framework describes five core areas for developing digital competence: *Information and data literacy, Communication and collaboration, Digital content creation, Safety* and *Problem-solving.* Particularly relevant in the context of this paper are the domains *Communication and Collaboration* and *Problem solving*, as they support the use of digital tools for professional interaction, patient communication and also identification of challenges and development of innovative solutions.

Teaching technology in health care education is not new, and many tried and tested approaches remain relevant. However, the increasing complexity and integration of digital systems call for a didactical framework that can span and integrate otherwise separate technologies and teaching approaches in order to build technological literacy among students. In the teaching that formed the basis for the observations and reflections reported in this paper (described below), the teaching activities were informed by the core concepts and practices of computational thinking (CT). CT was chosen as a theoretical background for planning teaching

aimed at strengthening students´ ability to understand, analyze, and adapt to technologies in problem-solving in a systematic and reflective manner (Weintrop et al., 2016), thereby supporting the development of these aspects of technological literacy. Through this approach, we seek to foster an educational environment in which students not only acquire knowledge about technology but learn to engage with technology.
The notion of CT has gained wide acceptance as relevant for the educational effort to establish fundamental knowledge and skills to formulate and solve problems in a way that can be effectively carried out by a computer and has as such been implemented in the compulsory primary and lower secondary school curriculum in 25 European countries (European Commission. Joint Research Centre, 2022). Although the application of CT has mainly been in teaching mathematics (Elicer & Lindenskov Tamborg, 2023), CT is increasingly recognized as a set of skills in various scientific fields (Weintrop et al., 2016), including BLS (Adler et al., 2023; Saqr & Tedre, 2019). There are, however, few published examples of how CT can be used in practical teachings sessions in higher education.

Theoretical background

The set of skills in CT involves problem-solving methods that leverage concepts from computer science, organized into the phases: *decomposition*, *pattern recognition*, *abstraction*, and *algorithm design* (Gross et al., 2014; Proctor, 2023). CT thus aims to foster algorithmic thinking that is applicable across disciplines, including health professions, and is therefore well-suited for technology focus in tertiary education in laboratory professions. Divided into the four phases mentioned above, the problem-solving skills can be accessed in an iterative manner, and learning situations can be designed and refined around them. *Decomposition* is about analyzing and breaking down the problem in order to strategically divide the work. Sub-problems can be identified, as well as dependencies between them. *Pattern recognition* entails generalization and characterization of phenomena, the context they exist in and their role in the solution. *Abstraction* requires the students to build a solid conceptualization, allowing them to focus on essential features while deliberately discarding the irrelevant. *Algorithmic design* is the creation of a sequence of steps, and also the critical revision and optimization of the result to shorten, speed up process or mitigate errors. In a learning environment, the CT-lens can allow students and teachers to analyze different strategies, solutions and technological variations not only to build knowledge and skills but also to discuss generic issues in digital problem solving.

CT can thus equip individuals to approach complex challenges methodically and innovatively. The integration of CT into daily practices (Wing, 2006) is encouraged to promote interdisciplinary innovation and prepare students for the dynamic demands of modern health and laboratory professions. The role of BLS at hospitals is to manage the production of diagnostic data whether the analysis is carried out in the laboratory, by other professional groups, or (increasingly) by patients themselves. Technologies applied in diagnostic laboratories often have short life cycles and become increasingly automated with each new generation. For example, in some laboratories blood sample analysis is fully automated, and the sample is not handled by staff. It is typically transported to the laboratory via a pneumatic type system, where it is automatically registered and analyzed by robotic systems. The diagnostic data are transferred to the central clinical information system. The role of the BLS staff is to support, monitor and solve problems that may arise. At the same time as this increased automation, health care services are moving closer to the patient's own home, requiring professionals to engage in communication and reflection around the use of technology and the problems that come alongside. We therefore see CT as a pivotal skill set for future BLSs, and a relevant approach for supporting and enhancing technological literacy, building on, e.g., Adler et al. (2023) who emphasize the connection between computational and technological skills. It can enable them to create, analyze, and interpret data visualizations, which are critical for understanding and solving real-world problems (Krakowski et al., 2024). By adopting CT, BLS students can improve their ability to tackle complex problems efficiently (Qin, 2009; Shoaib et al., 2019).

In the context of a three-week course for BLS students at University College Copenhagen (described below), we use CT to frame didactical approaches to actively engage students to discuss technology and enhance their creative and strategic thinking. Students are empowered to harness computational tools to address problems previously considered outside their domain.

The current study heeds the call for more examples of, and research into, applications of CT in higher education settings, as well as for new ways to teach technological literacy (TL). Other studies have evaluated effects of CT interventions by, e.g., post-tests and self-evaluation (De Jong & Jeuring, 2020); we here looked for evidence that students applied CT in our analysis of student actions in teaching sessions that were designed to support the students´ TL.

Setting

In Denmark, university colleges offer a 3.5-year professional bachelor program to become a biomedical laboratory scientist (BLS). The program combines theoretical teaching at campus with clinical training in hospital laboratories. Throughout their education, whether in clinical practice, theoretical classes or laboratory training, BLS students work to build competencies required for technological literacy (TL).

In the second year of the BLS program at University College Copenhagen, students engage in a three-week course specifically aimed at enhancing their TL. The course builds on prior teaching related to technology-handling skills during the first two years of the program, expanding these by explicitly using didactical approaches based on computational thinking (CT), and aimed at strengthening digital competencies. A key focus is on fostering a clear and precise understanding of central technological concepts, to support students in engaging with technologies in a structured and reflective manner. The course therefore aims to develop generic and transferable skills that enable students to enter an already digitized practice, navigate and adapt to a rapidly evolving technological landscape, and to remain relevant throughout their career in a dynamic digital professional environment.

The teaching plan

The course is titled *Technological Literacy;* the core elements are health diagnostic data flow, algorithm design, interface usability, automation through programming, AI in diagnostics, and the influence of technology on professional communication with patients. The student activities involve lectures, group discussions, hands-on workshops with robot programming and using a mobile telepresence robot, and a project exploring either the use of robotics or wearable technology in diagnostic practice. We selected three sessions for our examination, which highlight the practical application of these core elements and offer insights into how TL is integrated into the education of BLS; these sessions formed the basis for the observation (see Methods).

The broader learning goals aim to foster technological literacy through the development of problem-solving skills inherent in computational thinking (CT), in relation to technological solutions – such as identifying patterns and designing algorithms, programming algorithms for automated diagnostics, and critically evaluating user interface designs of in-vitro medical analytical equipment. To support this, CT inspires didactical approaches to support the development of these skills for breaking down complex problems and designing solutions. Drawing on Dewey´s (1938) *learning by doing* approach, these skills are developed through hands-on workshops, where students engage in practical problem-solving activities that mirror authentic professional challenges in laboratories and diagnostics. The first observed session introduces the basic task of automating a manual laboratory process. In the second session students engaged in solving a diagnostic problem through modifying algorithms in automated analytical diagnostic equipment. Finally, the third session shifted attention to the patient dimension, encouraging students to reflect on the implications of communicating with patients through technology.

Session 1: Flow-Robotics, programming a Robotic Pipette

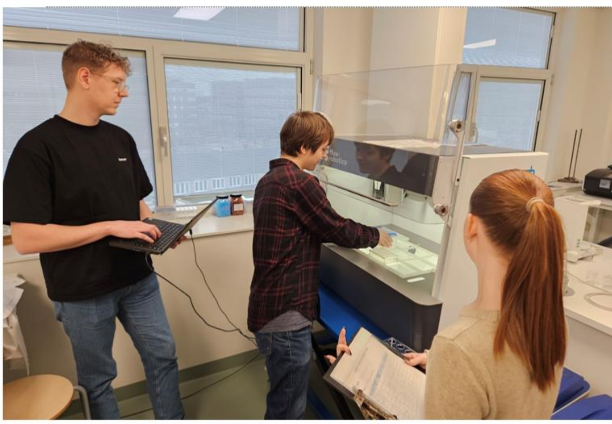

Figure 1. Session 1, students upload their program to Flow Bot One pipetting robot

The session is designed to engage students in a programming task with a clear and professionally relevant purpose. As an exercise aimed at developing TL, students are required to translate their manual pipetting skills into programming logic using specialized software (Figure 1). This involves *decomposing* the manual process into individual actions; *abstracting* and identifying each step in the craft of pipetting, *recognizing the patterns* of the software interface and finally producing a programmable *algorithm*, that mirrors the manual procedure in a digital format. Students work in groups in a workshop setting with a pipetting robot (Figure 1), that automatically handles liquids. In groups they are given three relatively routine pipetting tasks, which they are already familiar with performing manually in the laboratory. Using cloud-based software, the students are asked to program the robot to carry out the same procedures. The students upload their programs to the robot and observe the robot execute the task and reflect on the outcome. In order to successfully transfer manual laboratory actions into a programmable algorithm students must apply CT-skills, including decomposition, abstraction, pattern recognition and algorithmic thinking - all of which are central in this exercise. Equally important are the discussions about their experiences with the design and usability of both the user interface and the equipment. These reflections serve as a bridge to the next session which focusses on how to modify diagnostic algorithms.

Session 2: Programming automated blood analysis equipment.

This session is divided into three main parts – one focusing on CT skills and two focusing on design of software and equipment. The intention is that students draw on their experience and learning from the Flow-Robotics session (Session 1). They start out by discussing a clinical dilemma, where the routine algorithm for performing the diagnostic analysis on patient blood samples poses a substantial risk of delaying the medical decision for a subgroup of patients. The students in groups discuss and translate clinical scenarios into analytical diagnostic algorithms, that they formulate in the form of a flow-chart, using software; this is a task completed in the classroom. In doing this, students need to break down (*decompose*) the clinical problem and identify the essential analytical issues (*abstraction*) before an algorithm can be suggested (*algorithmic design*). The discussions with the teacher will include the clinical problem itself as well as the CT skills at play. The students then go to the

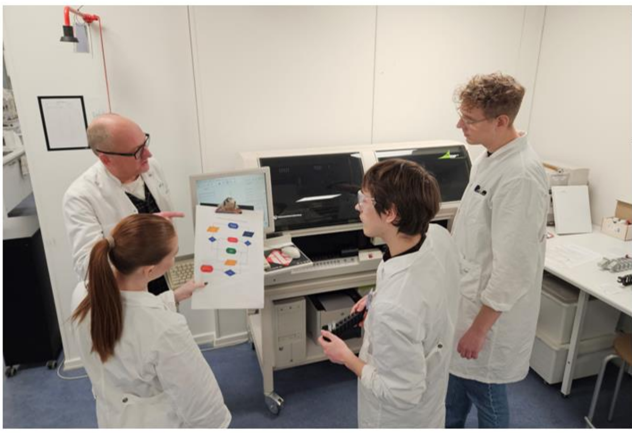

Figure 2. Session 2, students and teacher discuss how to program their algorithm using the software of the automated analyzer

laboratory and set up the automated analyzer with the relevant reagents while reflecting on the equipment's design using theory of principles for user interface design (Figure 2). Finally, students program the modified algorithm using the analyzer software, comparing its user interface with the software used in session 1 the day before and reflecting on the principles of user interface design.

The second and third part of this session (not observed) are the discussion of the theory behind user interface design as it relates to the design of the equipment and how it aims to prevent errors – and on the design of the software and how it differs from the design of the Flow-Robotics software.

Session 3: Telemedicine using Beam-technology
In this session, for which the design was to a lesser degree inspired by CT, the students are tasked with learning how to communicate with and instruct a patient on how to measure blood pressure at home, using a mobile telepresence robot with videoconferencing software. The learning goals for this session include the ability to describe the purpose of digital communication methods within a professional context, to effectively use video conferencing tools for communication and instruction, and to explain the principles of user interface design for medical communication devices.

The patient, represented by a retired staff member acting as such, is in a simulated living room on campus, while the students participate in groups via an online platform.

The session consists of three main parts. First, students reflect on the ethical considerations associated with the use of telemedicine tools, such as video conferencing, for communication. This is done in a classroom setting (not observed). Next, they engage in interactive communication with a simulated patient using a mobile telepresence robot (BEAM) (Blue Ocean Robotics, 2020). The situation and technology are new to the students, and the "patient" is instructed to exhibit various forms of non-compliance, all contributing to a complex problem. This requires the students to improvise and find solutions through the use of the robot. In a closing online debriefing with the teacher, the students reflect on their ability to communicate and provide adequate instructions through telemedicine.

Methods

Data acquisition

The observations analysed in this paper were carried out at a workshop in the Erasmus+ network *TechLit* which is aimed at developing teaching to support technological literacy for students of radiography, biomedical laboratory science (BLS), and chemical and biotechnical science. The approach included observations and reflections on the three teaching sessions for BLS students described above. As mentioned, these students are all 2nd year BLS students. The entire class comprised ca. 60 students; however, in the observed sessions either half the class or sub-groups of 3-6 students were present. Students and teachers were informed about the observations beforehand and gave oral consent.

The observers (who are also co-authors of this paper) were teachers and researchers from the three professions, from four countries. The observers represented different perspectives, as some understood Danish (the teaching language) and some didn't, and some were from a similar BLS education program, while others were from radiography or chemical and biotechnical science education programs. Each observation session started with a brief presentation of the setting and aim for the teaching. The observers were divided into two groups, each observing different sub-groups of students and/or parts of the sessions.

The observation and reflection data comprised three types of data:

1. One or two observers were tasked with performing in-depth field observations of each session, using a basic observation guide, which included focus on the environment, surroundings, atmosphere etc.
2. All observers were encouraged to note down, in free form, their individual observations and reflections, with a focus on when and how the students showed signs of TL *(i.e.,* understanding technology, using it effectively and critically assessing its risks and benefits to make informed decisions). This resulted in 9 individual observation datasets (in a total of 16 documents) of varying length and detail.
3. The observation and reflection notes were discussed in two reflection groups. This resulted in four data sets, one from each group on each of the two workshop days.

Analysis

The analysis was conducted drawing inspiration from Braun & Clarke`s (2006) thematic analysis and performed as follows:

Familiarization: All observations were read and reviewed thoroughly multiple times by a team of four experienced researchers, from Denmark and Norway, with research backgrounds in various natural sciences and didactics, three of whom had participated in the observations and one of whom had not been present at the workshop (giving an outside view of the data). None of the researchers analysing the observations had taken part in designing the activities. The purpose was to ensure a multifaceted understanding of the data and allow each researcher to note initial impressions and ideas, as well as aspects that prompted curiosity.

Coding: Through a systematic process, the researchers identified and labeled meaningful aspects of the data as initial codes. Following the principles of collective qualitative data analysis (Eggebø, 2020), the initial codes were collaboratively combined and refined by the researchers. This process served as the foundation for the subsequent analysis.

Developing themes: The codes were grouped into broader themes that reflected recurring patterns and connections in relation to the research question.

Reviewing themes: The proposed themes were revisited and refined to ensure they accurately captured the data and were aligned with the research aims. During this iterative process, the team engaged in discussions to reach a common understanding of the themes.

Defining themes: Each theme was clearly defined, with detailed descriptions and supporting evidence from the data. The names of the themes were carefully chosen to reflect their essence and relevance to the pedagogical framework.

Method strengths and weaknesses

We find it to be a methodological strength that we have many individual observations, from many different professional perspectives. The fact that some observers do not understand Danish may be seen as a strength because these observers were more attentive to non-verbal communication. It may be both a strength and a weakness that the two observer groups saw different students, as it sometimes led to observations pointing in different directions but also encompassed a broader range of activities. A weakness is that we observed relatively short sessions (ca. ½ hour at a time) and therefore may have missed some context for the teaching. Finally, some of the teachers in the observed sessions were new to these particular teaching sessions. This was because some of the regular teachers instead formed part of the observation group.

Results

Initially six coding focus points were used, derived from the aims of the teaching sessions: a-ha moments (for students and/or observers), motivation, student activity/behavior, teaching format, technological literacy. During the familiarization with the data and discussions of the analysis these focus points were consolidated to four: **Teaching format** (What and how, e.g. didactics or pedagogical framework). **Technological literacy** (digital skills of students, e.g., how they understand and utilize digital technology in the sessions, challenges and any gaps in digital literacy or technical barriers. **Student behavior,** this broad concept includes several subcategories such as: student motivation, activity, engagement, attention and collaboration. However, "Student activity" can also refer to specific actions students take, such as what they did during a learning lesson. **Aha-moments**, these moments represent instances of insight or understanding, often characterized by the recognition of connections and patterns and/or when something suddenly made sense. Additionally, we also considered if such moments increased student motivation and engagement. The category "A-ha moments" was also meaningful to work with in the analysis of the observation data.

From the labelled observation notes, using these focus points, we developed four themes that address different aspects of the research question:

1) Building foundational skills for algorithmic thinking and transfer across contexts
2) Motivation and engagement through active learning and tasks relevant for the profession
3) Navigating human-technology interaction: maintaining patient-centered care during technological operations
4) Enhancing metacognitive awareness through structured reflection on technology use

Analysis

Building foundational skills for algorithmic thinking and transfer across contexts

In all three teaching sessions there were elements that had to do with connecting knowledge and processes from analogue procedures with corresponding automated procedures. In the Flow-Robotics session, observations indicated that students, who appeared to have a thorough basic understanding of the manual processes involved in the exercise, found it easier to apply this to the algorithm for the robot. In CT-terminology, we found signs that these students were *decomposing* actions in manual laboratory work, using their knowledge of basic skills. Thus they "dissected a complex problem into manageable parts", as Shute et al. (2017) describe this aspect of CT. This is also reflected in the observation note that: *Lack of basic skills leads to frustration and difficulties completing the task*. This highlights that a clear grasp of the manual process is a prerequisite for effectively applying CT.

In the session where the students programmed automated blood analysis equipment, the teacher reminded the students of the manual exercise they had previously completed and thereby aimed to facilitate aha-moments by helping students connect theoretical knowledge with practical application, such as understanding the importance of terminology and/or the steps in algorithms. The aim was to help students draw on their earlier experiences to make sense of the programming task and help them generalize from specific examples and create clear, step-by-step instructions that the analysis equipment could follow. While CT methodological skills are also clearly emphasized in the objectives for the teaching session on automated blood analysis, it is here less clear (than in the Flow-Robotics session) to what extent the students in fact achieved these goals. In terms of CT, the aspects of *algorithmic thinking* and *abstraction* were seen in more teacher-guided sequences, where students were guided to apply sequential logic, while focusing on key elements of the manual diagnostic procedure relevant to the automated system. However, due to the teacher-guidance it is unclear from the observations how much the students independently exhibited these aspects of CT. Thus, as these sessions are more teacher-directed due to time constraints, there were less observable student activities indicating these skills in action.

In the Beam session, the students parallelized with a similar situation in the analogue world (from their own experience as home-carers). In this setting, however, this seemed to be a hindrance rather than a help in achieving technological skills, as these students expressed that they found the technology alienating relative to the patient. However, as critical assessment is part of TL, the students' reaction can also be interpreted as an expression of this competency.

By questioning the role and implication of the technology they demonstrate an ability to critically evaluate the use of technology in professional practice, rather than simply accepting the technology.

Transferring knowledge from one learning context to another was identified as challenging, highlighting the need to build this ability as a general competency. This difficulty underscores the value of CT (*abstraction*) as it might help students bridge the gap between familiar, concrete scenarios and unfamiliar, complex contexts. By developing these skills, students might be better prepared to apply their existing knowledge of analogue processes in new technologically mediated environments.

Motivation and engagement through active learning and tasks relevant for the profession

A key aspect of technological literacy is not merely to be able to operate existing technologies, but readiness to engage confidently and critically with new and emerging technologies (Adler et al., 2023; Jensen et al., 2024). A central finding both in observations and reflection notes was how teaching and the methodological frame can support the development of confidence and openness of the students. In the observations we saw how this can be supported by the didactical setting, e.g., when teachers guide or give feedback to students through different tasks either alone or in groups. It seems, from the observation notes, that such guidance and feedback helped students move forward, while the real life and meaningful tasks motivated students to participate actively, as seen in the observation note: *The students worked* <u>*actively*</u> *in small groups*. Observations indicated that innovative and curious students achieved the best results, while those who only followed instructions gained less from the exercises. In addition, it appeared that tasks that involved problem-solving and collaboration fostered engagement, which in turn seemed to enhance the learning experience. This is seen, for example, in the observation note that: *One particular group took a very exploratory approach, experimenting with different menus in the software*. Students laughed a lot and seemed engaged during exercises, even when the tasks were challenging, indicating that an atmosphere had been created where students could be relaxed and creative.

Other observations indicated that the students were training *algorithmic thinking*, by contextualizing the sequence of events in manual laboratory work into the formulation of algorithms (Shute et al., 2017). This was particularly supported by active learning approaches in the teaching design, where students were encouraged to *learn by doing* (Dewey, 1938), and by trial and error, and less supported in sessions, where the teaching was more teacher-directed. Some students struggled to see the relevance or link the knowledge to real-world contexts. They mentioned finding it difficult to see the transfer to the real world, even though efforts were made to emphasize this connection (see above). Additionally, some practical exercises were described in the observation notes as "like learning to drive," where mastering the tools overshadowed broader learning, corroborating the notion that students, who only followed instructions, gained less from the exercise.

Navigating human-technology interaction: maintaining patient-centered care during technological operations

In our observations and reflection notes, particularly of the session using Beam-technology for communication, we saw, as a central finding, the importance of being able to operate technology effectively while maintaining patient-centered communication. This was seen, for example, in the reflection note that: *The students were very occupied with technology and not so much with the communication part of the exercise*. Thus, some students struggled to combine operating technology with patient communication, and for example, "lost connection" with the patient while focusing on technology. As noted above, some students expressed that there was a contradiction between their professional roles as caregivers and the use of technologies. Thus, we saw that some students seem to be critical towards technology in patient interactions, as they perceived the technology as leading to less social contact with patients. As seen above, the results also showed that the (relaxed and safe) atmosphere in the exercise supported the students in experimenting and in reflecting, and that trial-and -error approaches were supported by the relaxed, pleasant atmosphere in the teaching sessions. Again, particularly students who are good at operating technology were inclined to experiment; these students also seemed more liable to find creative solutions and thereby master *abstraction*.

Enhancing metacognitive awareness through structured reflection on technology use

We saw that the students became oriented towards *problem-solving* when they reflected upon the use of Beam-technology. We saw that, in the structured debriefing sessions with student reflections after the Beam exercise, the students´ own reflections on their actions led them to express what they perceived as gaps in their own ability to balance technology use with patient focus. In line with Dewey’s view that learning emerges from experiences through reflection

(Dewey, 1910), these sessions appear to play a crucial role in helping students transform their practical experiences into understanding. Following on the findings above, a partial solution to this challenge may be implementing such reflection, or debriefing, sessions following directly on active, real-life simulated, use of technology. In the reflection sessions, the students were encouraged to discuss "pros and cons" of communication via technology and reflect on the experience from the patient's perspective. Students noted that technology removed some human interaction but also reflected on the timesaving and infection-control benefits of telemedicine. In these sessions, the students themselves discovered that they were not able to focus on the patient's needs and that they needed to be more familiar with the technology to be able to do so; this was seen as an "a-ha" moment for the students.

Perspectives

Due to the high pace of development in professional digital technologies new ways are needed to prepare students to thrive in this environment in their future professions. This is particularly urgent for technology-intensive professions, such as Biomedical Laboratory Science (BLS), Radiography and Chemical and Biotechnical Science, where technology is an integral part of daily practices. To meet these demands, there is a growing need to develop teaching approaches that strengthen students' technological literacy and problem-solving skills. The experiences described here are therefore relevant not just for BLS but for other education programs with a similarly heavy digital technology component and requirements for developing problem-solving skills for the latest technology (Adler et al., 2023; Saqr & Tedre, 2019). The network behind this study also comprises teachers and researchers from Radiography and Chemical and Biotechnical Science education programs, which are two fields with similar challenges and opportunities. For example, The International Society of Radiographers and Radiological Technologists (ISRRT) and the European Federation of Radiographer Societies (EFRS) stated that use of algorithms in clinical practice, such as AI, should be embedded in future curricula (The European Federation Of Radiographer Societies, 2020). Likewise, the Chemical and Biotechnical Science program mostly educates laboratory technicians for the Chem- and Bio-tech industry, where there is an increased use of robots and fully automated systems. This creates a need to emphasize TL in the education programs, so the students are ready to meet these changes.

We have used CT as a didactical frame to support student TL, while recognizing that CT also holds significant potential as a learning goal in itself. For example, Saqr & Tedre (2019) and Adler et al. (2023) argue that "due to the 2000's scientific techniques and technology, students will need to learn to see and interpret the world through computational and data-driven lenses". Supporting this view, Weintrop et al. (2016) emphasize the importance of embedding CT in science education, highlighting how it can deepen conceptual understanding through a system thinking approach and enhance student motivation when applied in an authentic context. Reviews indicate that, so far, little attention has been paid to CT in higher education (e.g., Lu et al. 2022) and that there is a need for more concrete definitions and implementations of CT within higher education to standardize teaching and assessment methods (Lyon & Magana, 2020). In higher education, CT is primarily aimed at computer science and taught through programming tasks, while unplugged creative approaches are less frequently used. Both approaches, however, have been shown to foster problem-solving skills (De Jong & Jeuring, 2020). Therefore, continued research and innovative didactical strategies, such as those suggested here, are essential to fully realize its benefits.

Our analysis indicates that supporting students in developing TL by recognizing *patterns*, *abstracting* key concepts, and applying their domain-specific knowledge across technological contexts is key to developing central generic and transferable technological competencies. In addition, the hands-on approach not only reinforces students' attention to the analogue process but also encourages a deeper engagement in the underlying logic and structure inherent in the professional task. Thus, by integrating the *learning by doing* philosophy (Dewey, 1938) we find that the abstract principles of CT become more concrete and accessible. By incorporating principles from Situated Learning (Lave & Wenger, 1991), such as *community of practice*, defined as "[....] groups of people who share a concern or a passion for something they do and learn how to do it better as they interact regularly" (Lave & Wenger, 1991), together with the development of "real-world-contexts", facilitation of *communities of practice* may enable the students to engage across classes and over time and connect the learning activities more explicitly to their professional applications.

The analysis also points to the need for strategies that help students reconcile their professional identity with technological advancements, ensuring that technology enhances, rather than hinders, patient care. In our teaching, this included a focus on the *Collaboration and Communication* domain of the DigComp 2.2 framework, which emphasizes the ability to interact through technologies. Verbeek (2006) argues that technology mediates human action and perception, shaping how individuals interact with both their environment and others. In a healthcare context, this mediation affects professionals' interactions with technology and patients alike. Consequently, teaching students how technology shapes their perceptions and interactions within healthcare settings is critical to ensuring that technological skills are integrated seamlessly into patient care. This is further supported by Anil et al. (2023), who emphasize the necessity of defining and evaluating telemedicine competencies in education and training, highlighting the importance of preparing healthcare professionals to deliver efficient, high-quality telemedicine services. Bajra et al. (2023) also stresses that telemedicine competencies can be effectively taught through structured curricula, with simulated encounters leading to a positive shift in students' attitudes toward telemedicine. Our study supplements these findings, demonstrating that while students showed growth in their perspectives on telemedicine care quality, many still struggled to address its limitations. This suggests that further training is needed to help students bridge the gap between technological competence and patient focus. Incorporating even more metacognitive reflection could help deepen students' understanding of both the technical and interpersonal aspects of their roles. The goal is to help students integrate technological skills with their professional identity, ensuring that technology enhances patient care. One potential solution to this challenge could be to design the exercise with a foundation in CT. By engaging students in *decomposition* and *abstraction* prior to the digital activity, they might be encouraged to break down and analyze the analogue process, identifying which parts of the interaction are critical to patient care. This step might help students develop a clearer understanding of digital communication, enabling them to balance technology use with patient centered communication.

Conclusion

This study explores the value of computational thinking (CT) as a didactical framework to support the development of technological literacy (TL) in technology-intensive education programs. Our findings show that students with a thorough understanding of the underlying manual processes are better prepared to engage in algorithmic thinking and to transfer knowledge across analogue and digital contexts. However, the transfer of knowledge across contexts remains a challenge, stressing the need to design learning activities that explicitly promote the CT elements *decomposition* and *abstraction*. Furthermore, the study underscores the value of hands-on, professionally relevant activities, as student engagement was most evident when students were allowed to explore real life tasks. While some students thrived through exploring, those who simply followed instructions seem to benefit less - suggesting that a CT-informed active learning approach may support the development of TL. Additionally, deeper metacognitive reflection may help students integrate technical and interpersonal skills, ensuring that technology is applied in ways that support patient care.

Taken together, the findings suggest that, by embedding CT methodology into teaching practices, educators can support students in engaging critically with technology, so that it enhances, rather than disrupts practice.

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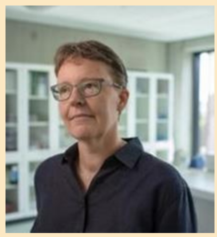

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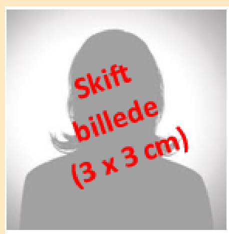

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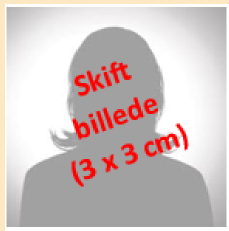

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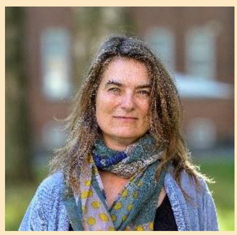

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