

Teamwork analytics for training collaborative problem solving in professional higher education (TeamLearn)

1. Excellence

The TeamLearn project will develop and investigate an approach for capturing evidence of teamwork to effectively support collaborative problem solving in medical interprofessional, nursing and legal education. Collaborative problem solving and effective teamwork in education or industry are key for employability and lifelong learning [33][35]. Preparing graduates for collaborative, knowledge-based work is therefore an issue of general concern. Collocated teamwork, in which participants share the same physical space but use advanced technologies to solve (acute) problems, remains a pervasive practice across domains, despite the online revolution. Hence, research about how automated feedback using teamwork analytics generated through computational means can assist students and teachers is crucial for good learning and effective guidance.

The project will study how collaborative problem solving can be supported by providing automated feedback to collaborating student teams about their teamwork during and after team-based activities in high-fidelity professional simulations, in medical interprofessional, nursing and legal education. Student team activities will be closely examined using a research design that combines exploring digital traces of the teams' communication, actions, positioning, affective states, use of digital tools and post-event reflections with interventions intended to enhance learning. To this end, the project will develop a tool for automated feedback, methods and instruments for use in formative assessment and guidance of students' collocated teamwork, by making teamwork traces available for multimodal computational analysis and subsequent visualisation interfaces. The project aims to transform collocated teamwork, currently an ephemeral phenomenon and largely opaque to computational analysis, into one from which salient features of students' teamwork can be captured and rendered visible and used as real-time input to support their learning. The project's outcomes will be of international academic interest: addressing growing interest in moving beyond the sole assessment of cognitive ability by enabling the authentic assessment and development of 21st-century skills.

1.1 State of the art, knowledge needs and project objectives

The TeamLearn project builds on research in professional contexts where effective collaborative problem solving is critical [7][21][38]. Collaboration is becoming increasingly prevalent as societal issues involve multiple stakeholders and the importance of skilled teamwork has been widely recognised as critical to effectiveness, innovation and wellbeing in a modern global economy [12][24][33][35]. These contexts may involve verbal exchanges between different experts, as in team discussions about diagnosis and treatment of a difficult case in a hospital, or concerted verbal and physical action, as in a crisis situation in the operation room. In such contexts, a mistake could have serious consequences and solutions require the integration of group achievements with team members' idiosyncratic knowledge. How well a team performs in solving the problem is usually validated based on a successful outcome [7][15][27]. As new technologies and methods emerge in the field of capturing and analysing digital collaboration [26], new opportunities arise that can enable education to facilitate students to learn and solve problems collaboratively and effectively. However, there is limited research about how teams can learn to perform well in authentic settings, when guidance and assessment and guidance of team learning and performance is provided *during* problem solving, enabled by digital technologies. To study this, in TeamLearn, we distinguish collaboration as a *method* to support learning (e.g., through teamwork) from the *process* that generates a solution to a problem, referred to as collaborative problem solving (CPS).

CPS in team settings has been examined through various national and international assessments at elementary, high school, and tertiary levels [17][18][35]. Generally, CPS has been shown to facilitate increased student engagement through the exchange of verbal and non-verbal cues and higher-quality communication processes, which improve productivity in completing difficult tasks [8][17]. Teamwork can encourage individuals to externalise their personal perspectives to reach a shared understanding [18], while CPS supports development of critical thinking, complex concepts through idea exchange and creativity [41]. CPS and team-based learning (or teamwork) are often employed in professional higher education programmes, such as healthcare, engineering or informatics, where learning activities frequently consist of collaborative, authentic problem-or project-based sessions [5][10][38]. In nursing and medical education, team-based learning and problem solving are a common form of training students in specialised and teamwork skills, often in high-fidelity simulation settings [5][7][15]. Studies have demonstrated the positive effects of CPS, such as increased knowledge of complex pathologies and patient profiles, problem identification, clinical reasoning,

coordination, and communication skills [7][38]. Reflection after simulation sessions is valuable in learning patient-care behaviour and stimulating knowledge consolidation but often uses limited data (e.g., video recordings) [45]. In legal education, studies of team-based learning have generally been single case or survey-based studies, exploring learning designs and students' experiences [40]. Students and staff in legal education consider team-based learning an effective model for engaging cognitively and enhancing teamwork skills and confidence, but raised concerns about group tensions and dynamics. Furthermore, technology-enhanced teamwork and innovation have been implemented sporadically [20][30], but with positive effects on learning. Furthermore, a recent review [23] found that clear measures of individual or team behaviour are lacking in CPS, and a significant amount of faculty time and expertise is required to implement it effectively.

When implementing CPS, we need to coordinate, listen and speak, act, share, initiate and react towards and with others. Doing these well is good for learning, but doing these well as a team also requires learning [1]. Generally, assessing and guiding the progress and quality of CPS and of teamwork activities is difficult and time consuming. In higher education, performance assessments include peer-assessment or self-evaluation surveys, think-aloud protocols, or rubrics [6][31]. Studies focusing on qualitative aspects of CPS processes, while insightful and applicable in particular settings, lack generalisation and scaling potential [5][10]. Importantly, all of these assessments are labour-intensive and lack the potential to provide a holistic view of the complex teamwork processes taking place during CPS. Furthermore, due to the digitisation of work and education, CPS and teamwork require the integration of knowledge across multiple interconnected systems distributed across people and machines [19][37][46]. Consequently, it is challenging for facilitators and participants in teamwork to assess and improve performance in authentic situations, as they commonly have sparse evidence to promptly identify issues arising as effects of team's various actions or interactions [17][46].

Making evidence of CPS and teamwork, collocated and mediated by digital technologies, available and visible is an effective strategy for team skills training. While there is abundant evidence of CPS and teamwork's importance in learning, ways of automating measures of teamwork and providing timely guidance are scarce, especially in authentic settings [8]. Collaboration analytics and multimodal analytics offer opportunities to facilitate sensemaking of multimodal data related to such phenomena. These techniques and approaches allow the automatic or semi-automatic capturing, analysis, and distillation of data about collaborators' speech, actions, and interactions. A growing body of work utilises behavioural traces of human activity captured through behaviour or learning analytics [14][18][37]. These traces range from low-level logs, such as clickstreams, to non-mediated human actions, such as eye movement, physiological measures, or gestures. Different categories of verbal and non-verbal indicators have been used to measure the quality of collaborative activities, ranging from tangible interaction (e.g., gesture, posture, and head or hand orientation), different speech-based cues (e.g., non-lexical speech features, speech-activity features, and speaker-based features), to gaze and eye interaction [37][2][28]. Logs are easily captured at scale without observers influencing the activity and mined using data science techniques to cluster and visualise behaviours. Methods of collecting automated, fine-grained data and performing team analytics can facilitate scalable feedback, assessment, and reflection [27], typically complex, laborious, and unattainable in the time-bound CPS process.

Knowledge needs. Despite substantial advancements in digital technologies used for teaching and learning, also in connection with the online pandemic teaching, and of automated data-mining, research-based knowledge that could be used to timely and effectively support teamwork and improve CPS is limited. The primary need is to automatically collect quantitative team data grounded in semantics derived from a qualitative interpretation of team interaction and its (disciplinary) context. Yet, despite the growing body of research focusing on multimodal data input in higher education [37] and the workplace [32], analysing collocated CPS has not been explored extensively in authentic settings (e.g., intensive care units, simulation rooms or trials) and has not been combined with qualitative data to understand the collaborative process in-depth. Research knowledge and methodologies to connect the multimodal data to context- and domain-specific knowledge and actions are clearly lacking. Furthermore, a critical underexplored challenge is facilitating sensemaking of multimodal team data, combined with qualitative accounts of CPS, for (formative) assessment and training in authentic learning situations. Our team's research has included the use of technology to automatically capture multimodal behavioural traces (e.g. speech, gesture, indoor positioning, or object manipulation data) [14][26][28][29][41] and the in-depth qualitative analysis of team interaction in academic disciplines and the workplace [9][10][11][25]. Combining these different data sources and techniques applied in our research into an integrated analysis has the potential to generate distinctive insights into what happens when students create unique paths to solve problems, interact with peers, and act in both the physical and digital world [46]. Such complementary traces and analyses of learning activity can lead to gaining a more

robust understanding of the collaborative problem solving process, which could then be used in ecologically valid measurements, assessment and guidance approaches.

Project objectives. In the TeamLearn project, we propose to develop a better understanding of CPS in three professional higher education programmes: medical interprofessional, nursing and legal education. These programmes are selected because their curricula contain a variety of team-based learning activities, and prepare graduates for professions where CPS competence and teamwork are critical. Finally, these professional contexts are imbued with digital technologies, which generate opportunities for gaining a better understanding and for augmenting practices. We will collect and analyse low-level multimodal analytics (i.e. digital traces) of teamwork, combined with in-depth analysis of teams' interactions, and we will construct indicators of teamwork and collaborative problem solving, which can then be modelled to computed multimodal teamwork analytics. We will then examine how visualisations resulting from this modelling (i.e., multimodal analytics dashboards [MAD]) could provide real-time feedback for students engaging in CPS activities and prompts for in-depth reflections on team performance. To this end, the project's **objectives** are as follows:

- PO1. Develop methodologies and indicators for the real-time feedback and guidance of teamwork in collaborative problem solving in professional education;
- PO2. Adapt, test, and implement a learning tool for providing automated feedback based on multimodal analytics on teamwork during learning collaborative problem solving;
- PO3. Generate knowledge about the effects of interventions and learning designs based on multimodal teamwork analytics on the collaborative problem-solving process and outcomes;
- PO4. Develop and disseminate knowledge and instruments based on multimodal teamwork analytics to support collaborative problem-solving and teamwork across professional education contexts.

1.2 Research questions and hypotheses, theoretical approach and methodology

The research will examine how a gradual understanding of automated feedback through MAD can enable effective teamwork and students' CPS competence development. To address the identified knowledge needs, TeamLearn will answer the following **research questions**:

1. What are the relevant characteristics and measurable indicators of CPS in medical interprofessional, nursing and legal education, and which multimodal data types are needed to capture them empirically?
2. How can automated feedback provided through multimodal analytics dashboards assist students in self-assessment and development of teamwork skills for CPS?
3. What are the effects of and experiences with using automated feedback and structured reflection on student teams' CPS performance?
4. What are the differences in the use of a multimodal analytics dashboard across and within three professional education programmes?
5. What types of skills should students attain in order to use automated feedback on teamwork effectively?

The empirical examination builds on a conceptualisation of CPS based on established models of problem solving and [6][17][18] and sociocultural notions of mediated learning [43]. While different CPS frameworks might use different terms, they all emphasise **establishing shared knowledge** to generate a solution and **maintaining a functional team** [6]. The former concerns cognitive, or task-related activities, such as *defining the problem, identifying gaps between required and existing knowledge, exchanging ideas, proposing alternative solutions, and integrating ideas to generate solutions*. The second dimension is fundamentally social, comprising *communication, coordination, monitoring of progress and results and resolving divergence and misunderstanding*. There is a need to manage relationships between participants, their actions, tools and materials used in these actions, and the effects that these actions produce. CPS requires that these elements are made transparent to most or all members of the team and that a transparent, visible, shared vision and series of updates are available and enable a team to engage in solving problems collaboratively [6][17]. Furthermore, the notion of **mediation** highlights the fundamental idea that learning and activity are of performative nature and are mediated by tools [43]. Examples are representational tools or visualisations of a team's joint work [29] or particular artefacts developed in collaboration, such as essays or prototypes [9][10]. Tools and artefacts can contribute to the externalisation of individual processes of sensemaking into the observable, intersubjective world and become structuring resources for learning; however, to become useful for the learners, they should be elaborated on and developed through action, within a team's collaboration context.

Research design, methods and instruments

In TeamLearn, we will work with courses or modules (hereafter, 'cases') in three professional programmes at two higher education institutions in Norway. In each case, we will form small teams of two researchers and 2–3 teachers or lecturers, who will also act as co-researchers. Approximately 160 students will be involved in all

phases of the research. In each case, we will work with teams of teachers to connect with and influence more deeply the local teaching and educational design practices [36]. The length of the project allows for iterations of empirical studies, revisions of designed material, and opportunity to collect longitudinal evidence.

Case 1. Medical interprofessional learning for students in clinical practice: Primary healthcare providers assume responsibility for patients with complex problems often requiring interprofessional teamwork. At the University of Oslo (UIO), such training is organised in the course Sampraks¹, a collaboration between four faculties and programmes in health and social care education. Medical interprofessional teams of 5–6 students work with simulation scenarios of common, sub-acute patient situations and collaborative problem solving. Students are challenged to apply their knowledge in practice, collaborate, and improve their clinical judgment. The case emphasises how participants build the capacity to collaborate, engage in sharing information and explain and elaborate on concepts to solve the immediate problem and collaboratively prepare for future care.

Case 2. Simulation Unit in nursing education: At the University of Southern Norway (USN), simulations are used frequently to train students for clinical rotation. Simulation using different types of manikins has been enhanced through advanced computer programs with virtual or digitally-enhanced patients. This case consists of a clinical course in a blended learning environment, using the ‘Body board’ functionality of the simulator *Body Interact*TM. BI includes a variety of expert-reviewed patient scenarios, ranging from sub-acute patient situations to intensive care resuscitation cases. Each scenario begins with a brief description of the virtual patient’s clinical history and ends with a debriefing to reinforce key concepts. Students work in teams of 3–5 with facilitation by faculty, in three-four recurrent sessions using different patient scenarios.

Case 3. Moot court and legal procedures: The Faculty of Law at UiO is currently integrating experiential learning modules into the Master of law programme. Almost all modules involve group work and team learning. This case will connect to modules teaching trial skills, appeals to contractual negotiation and ethical roleplays. The Moot court and Procedure competition courses² provide a case in which students learn to prepare for pleadings, conduct oral submissions in connection with a main hearing and engage in classic dispute resolution situations through practical-oriented tasks. In the Procedure course, student teams prepare and participate in a moot trial competition. Preparation activities for these competitions are ideal settings for training (and studying) teamwork and collaborative problem-solving skills. The technology supporting the collaborative work will be TalkWall (<https://talkwall.uio.no/#/>), a digital platform for facilitating discussion and idea sharing, which generates digital ‘process and product’ traces.

The **design-based research approach** in TeamLearn will use is grounded in a collaborative partnership between educational researchers, computer scientists, teachers, and technology developers [39]. The design-based approach involves several cycles of (1) data collection, (2) analysis and evaluation, and (3) re-design and adaptation, a methodology known as *design experiments* [36][39]. Interventions will include automated-feedback enhanced CPS activities in real educational contexts (i.e., the three cases). This systematic approach informs the development of ‘products’—MAD **tool** and **learning scenarios**, employing research findings in combination with iterative deployment. The interventions, procedures and tools will be flexibly developed during the project. Teachers in the three cases will act as co-designers by tailoring CPS tasks to domain-related professional practices, developing new problem descriptions (e.g., patient pathology, legal problems) and activities (e.g., simulation scenarios, moot trial tasks), and adapting digital and physical resources to task needs. Design principles and models will reflect the authentic conditions teachers and students operate in. The co-design and empirical studies will take place in three main phases, described in detail in Table 1 (on page 5).

We will address the research questions by combining **quantitative** and **qualitative research methods**. CPS competences cannot be ascertained through studies focusing solely on analysing pre- and post-intervention data. By collecting and analysing data at various levels of behaviour and interaction, moment-by-moment and over time, we can investigate how students orient themselves in technology-supported environments and in relation to complex problems. This approach allows us to specify how CPS occurs in different knowledge domains, the conditions under which teamwork becomes conducive to CPS, and the dynamic contexts of CPS, whereby participants construct solutions through combined individual knowledge and joint team actions [11]. Working on this micro- and intermediate level, with different data, can also explain the links between processes and outcomes over time [9][36]. We acknowledge that this project does not have a causal design, and numerous variables could affect students’ progress in a course context. However, the quantitative elements of the analysis will help establish whether students have made progress in CPS. Also, linking this approach with quantitative analysis of collaboration will make possible a larger-scale implementation with well-developed, empirically-based models and materials.

¹ <https://www.uio.no/for-ansatte/enhetssider/mn/aktuelt/aktuelle-saker/sammen-i-praksis.html>

² <https://www.uio.no/studier/emner/jus/jus/JUS5040/index.html>

Table 1. Project phases and activities

Phase 1. Generating teamwork indicators	
Goal: Elicit users’ conceptions of and experiences with teamwork and CPS, as well as needs for support; identify success criteria for good teamwork and quality of CPS processes and content in disciplines (RQ1) Approach: Bottom-up, exploratory empirical work and a literature review. Outcomes: Success criteria for CPS, Indicators of process quality, Conceptual framework for CPS Guiding questions: <i>What aspects of teamwork should be measured? Where does team self-assessment and guidance happen? When does assessment and feedback provision occur?</i>	
A1: Empirical explorations	Data: Focus group interviews, Surveys Observations Field notes, images, audio recordings of meetings, and artefacts Analyses: Thematic analysis Epistemic Network Analysis (ENA) Statistical analysis
The study explores students’, teachers’ and other relevant stakeholders’ conceptions of and experiences with CPS and teamwork activities, as well as their needs for support. <i>Work form:</i> Data collection through interviews with teachers, survey of students, and observations of existing simulation/teamwork sessions.	
A2: Co-design of CPS indicators, guidelines and templates.	Analyses: Thematic analysis Epistemic Network Analysis (ENA) Statistical analysis
Researchers and co-researchers develop indicators, which are <i>observable behavioural markers</i> that provide information about the quality of team’s CPS actions (e.g., sharing information in a simulated resuscitation situation is indicative of idea exchange). Indicators identify underlying ideas about and pedagogical intentions related to guidance of CPS and teamwork. They will be used in subsequent phases to (a) adapt the MAD tool, (b) co-design learning scenarios for CPS, and (c) aid in measuring the quality of the CPS process and content. <i>Work form:</i> Two-hour co-design sessions with researchers and case leaders, 2–3 teachers and 3–5 students per case.	
Phase 2. Co-design and trials of interface and learning scenarios	
Goal: Generate solutions for presenting analytics of teamwork in a form (automated feedback) that makes sense for users (RQ2), as well as learning scenarios for authentic settings. Approach: Adapt (co-design) and pilot an interface for automated feedback based on model from Monash Outcomes: MAD for feedback and learning scenarios. Guiding questions: <i>What indicators are best displayed to users? How should information be displayed and when? How are students and teachers using MAD?</i>	
A3: Adapt the existing MAD.	Data: Field notes, images and artefacts (e.g., prototypes) Usage logs: location coordinates (Case1), affective states, object use actions Audiotaped and Videotaped CPS sessions; Short (10 min) interviews Analyses: Thematic analysis Statistical analysis of log data ENA
The original computational model of multimodal teamwork analytics developed at Monash University will be adapted to the Norwegian context. The model encodes low-level multimodal team data (automatically using sensors, microphones, and video cameras) into intermediate knowledge structures (indicators) associated with teamwork, to be displayed on an interface (MAD) as automated feedback. Feedback is provided based on rule-based algorithms detecting the order and timing of actions (e.g., communication frequency, tool use, affective states) via visualisations, charts or text. <i>Work form:</i> Modelling, computing by EngageLab and Monash developers.	
A4: User trials of adapted MAD based on prototypes	
MAD prototypes presenting processed data as feedback to prompt teams’ self-assessment and reflections on teamwork activities will be tested with students and teachers. <i>Work form:</i> Usability sessions (25-30 min) with 6–9 teams of 4–5 students and teachers in each case; 40–50 participants in total.	
A5: Co-design of learning scenarios for CPS.	
Researchers and teachers develop or adjust together CPS scenarios for the three cases to include automated feedback and enhanced reflections. Scenarios contain learning goals description, activities for all participants, types of feedback, materials, and types of guidance envisioned. The scenarios outline <i>two types</i> of automated feedback through MAD: (a) real-time self-assessment with feedback based on MAD and (b) post-event debriefing and reflection using MADs and annotated videotaped team performance. <i>Work form:</i> Co-design sessions with researchers, case leaders, teachers.	

Phase 3. Scaled empirical studies and implementation	
Goal: Examine empirically the interventions, use of automated MAD-based self-assessment and guidance, and its influence on CPS process and performance (RQ3, 4, 5) in authentic settings. Approach: Scaled empirical studies conducted over two semesters. Outcomes: Validated learning scenarios, tool and knowledge with dissemination potential. Guiding questions: <i>How can interventions be coordinated and monitored? How can automated feedback-enhanced teamwork be organised at scale? How can the collaborative analysis of data be organised?</i>	
A6. Design experiments – empirical studies Design experiments [36][38] are a viable model for incorporating participants' input and actions, and theoretical prescriptions. These are realised by implementing redesigned scenarios, using MAD-based feedback, in the settings of the three cases. Two iterations allow scaling the designs, creating a basis for generalising findings in similar empirical contexts. First iteration involves a <i>post-event intervention</i>, where MAD-based feedback is provided in a debriefing after the CPS session. Teachers and team members are prompted to reflect/assess on team performance [45]. MAD-based feedback and annotated video footage of team functioning (corresponding to MAD samples). Second iteration follows the same procedure, with MAD-based feedback provided in <i>real time during CPS sessions</i>. Teams are asked to pause their activity and examine the automated feedback provided visually before resuming the activity. At the end of debriefing sessions, teachers and students are asked to <i>score</i> their CPS performance and experiences using a standardised scheme, and students to complete a questionnaire on their experiences with CPS. Work form: CPS sessions, 15–20 teams of 4–5 students, case teachers, total of about 120 students; by mixed teams of researchers and case leaders, EngageLab developer.	Data: Usage logs; location coordinates (Case1), affective states, object use actions; Audiotaped and Videotaped CPS sessions and debriefings; CKP survey and CPS scores Analyses: Statistical analysis Epistemic network analysis Thematic and interaction analysis
Phase 4. Dissemination and exploitation activities (detailed in section 3.2 and online portal)	

Data collection, processing and analysis will be coordinated by the PI's institution, and conducted together with local partners. Co-analysis of data (e.g., through data workshops) is critical for addressing the implications of the study for the partners and other stakeholders, and will provide feedback for further development. The project activities will generate a rich set of data, which will provide a comprehensive understanding of both the processes and outcomes of teamwork and CPS, as well as the effect of the developed tool in educational settings. Figure 1 illustrates data collection in simulation settings in nursing education, in a study by Monash University [14] [28], partner in this project. Data types and planned analysis purposes are shown in Figure 2.

A combination of **quantitative analyses** will be conducted, with a novel approach where Epistemic Network Analysis (ENA) is combined with analysis of multimodal data. ENA is a quantitative ethnographic technique that enables the analysis of logfile data in collaborative learning [41][42]. It can model connections between occurrences of assigned codes within a relevant unit of analysis (i.e., turn-taking in dialogue) at both the individual and team level in the same analytic model. ENA will be performed to analyse the connections between affective states, particular special regions, and actions used by the participants. ENA will also be used to analyse connections between affective states and indices of social and cognitive processes that will be identified through the in-depth qualitative analysis of team verbal communication and the use of domain-specific concepts during CPS and debriefing sessions. Multimodal log data will be analysed with techniques used in *data mining and learning analytics*.

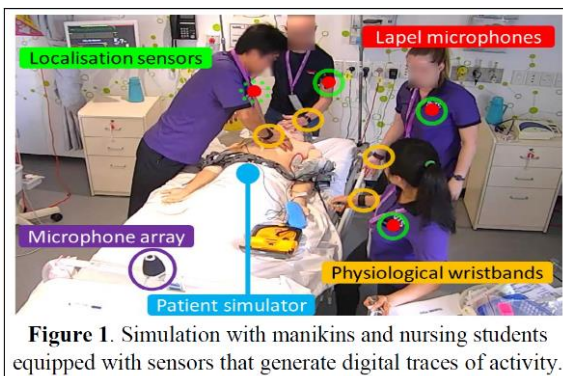


Figure 1. Simulation with manikins and nursing students equipped with sensors that generate digital traces of activity.

Data collection	Data types	Data Analysis	Intervention
Co-design studies (P1-2)			
Interviews, Observations, Artefacts, Images Audio recordings		Thematic analysis ENA	Co-design of MAD & scenarios
Empirical studies (P3)			
Real-time, automated measures	Physiological functions Location coordinates (Patient functions) Team communication Video	Computational, Markov chains, process mining Learning analytics Epistemic network analysis (ENA)	Real-time
Post-event qualitative measures	Debriefing protocols & video Interviews	Thematic analysis Analysis of interactions	Post-event

Figure 2. Overview of data types, analyses an intervention

Location based coordinates will be descriptively analysed with *heat maps* to understand patterns of the usage of the space and relevance to objects/tools and other participants. To unveil affective states, physiological time series data will be analysed with *hidden Markov models* and *time series clustering* techniques [16]. Manipulation with objects will be analysed with process mining techniques including *Markov chains* and *fuzzy miner* to uncover patterns in the connections of actions taken by different team members and compare teams [16]. **Statistical analysis** will be conducted on students' self-assessments and experiences with the enhanced CPS activities, measured through two combined validated tools: a scoring scheme for assessing complex problem solving [6][19] and the adapted Collaborative Knowledge Practices Questionnaire of knowledge-work competence in education, in collaborative assignments (CKPQ) [31]. Associations and effects of interventions will be examined through correlation and regression analysis.

Qualitative analyses will examine CPS and debriefing sessions in-depth. We examine selected excerpts from focus group interviews and co-design discussions through a multi-step **thematic analysis** [3] and a two-fold interpretative lens: (a) a topical content (the 'what') lens to identify the knowledge, ideas and experiences activated during CPS and (b) a procedural content (the 'how') lens to identify approaches, methods and tools used for problem solving [9]. **Analysis of team interactions** will be conducted through a micro-analytical examination of (audio, video) recordings of teams' CPS and debriefing sessions, to examine in-depth how students interact with each other, the task elements and the digital-material infrastructure [3] [22]. An open, interpretative approach will allow us to account for institutional features that characterise the CPS context: what is relevant, what has an impact on team actions, and why. *Mediation* will function as an empirically sensitive concept to interpret how teamwork and interaction are managed moment-by-moment and over time. We will use NVivo to develop codes inductively to show how interactions using the automated feedback unfold and how these relate to students' problem solving as a team.

Ethical considerations. We will obtain informed consent and handle all data collected according to the GDPR and ethical guidelines as defined by NESH. We will develop a data management plan, giving special attention to the matters related to collecting digital traces. Project staff will be trained accordingly. We will use UiO's Services for Sensitive Data (TSD) to store data securely, with data sharing restricted to project members.

1.3 Novelty and ambition

The TeamLearn project is novel as it tackles a key challenge at the intersection of learning sciences, learning analytics, and educational design, by combining information about different verbal, physical, and interactional processes at different spatial and temporal scales. The field of learning analytics is dominated by research where often a single data modality is associated with interpretations of complex processes. Although data logs can illuminate what students do, they often say much less about why. The project is novel and ambitious *methodologically*, as it addresses the absence of theoretically-grounded analytics innovation in learning contexts. It attempts to create methodologies and interpretations based on infusing low-level multimodal data with contextual meaning through qualitative accounts. This approach will develop principled ways to make sense of student-interaction data available through analytics, but not stripped from its educational and disciplinary context. At *empirical level*, this project is novel because it will visualise, analyse and interpret evidence of teamwork with significant potential for research, and for academic and professional learning. This project requires an advanced design and analytical approaches that can enrich quantitative data streams with the qualitative insights needed to interpret them. The empirical novelty is an understanding of collocated teamwork and problem solving by integrating multimodal analytics techniques and qualitative insights, as well as assisting researchers in testing theories about what makes teamwork effective. Finally, at the level of *educational practice*, the project generates novel pedagogical and digital solutions to help educators and team members reflect on teamwork and CPS constructs, and policy makers to devise strategies based on evidence.

2. Impact

The TeamLearn project will have a **long-term impact** on (a) *educational research*, through empirical knowledge about using automated feedback to effectively support teamwork and CPS, and (b) *social research methods*, through knowledge on combining multimodal and qualitative data to examine teamwork. The project will have a **short- to mid-term impact** on (c) *educational practice*, through new tools and instruments developed to support more effective teamwork and CPS in education and (d) *policy making and leadership decisions*, through recommendations for innovations to support development of teamwork skills and CPS competence. The project has significant potential to also impact (e) *industry*, as teamwork and CPS skills and analytics solutions have potential to contribute professional and lifelong learning.

2.1 Potential academic impact of the research project

The proposed research addresses a global problem, and it could significantly impact the international research community by stimulating research, teaching, and learning innovations worldwide. The project will generate new knowledge and an automated means for capturing evidence to assess and effectively support CPS and teamwork skills. It will craft the building blocks for facilitating customized services in physical learning spaces, through personalised feedback and data-informed guidance strategies. The project's outcomes will be of international academic interest: addressing the growing interest in moving beyond simply assessing cognitive ability by enabling the authentic assessment and development of 21st-century skills through integrated analyses. In particular, the project's outcomes will be of value to researchers in several fields:

- In the field of educational sciences, computer-supported collaborative learning and teamwork science, the project will provide methodologies to study teamwork and create interfaces to support teams effectively.
- In the field of learning analytics, artificial intelligence (AI) in education and healthcare and legal education, the project will provide much needed research applied in authentic settings in which complex data streams can be captured by using data to develop educationally meaningful constructs.
- In the field of design, the project will provide methodologies for engaging with critical educational (and other) stakeholders to co-design data-intensive innovations.

2.2 The research project's potential for societal impact

While the TeamLearn project's context is healthcare and legal education, our research could significantly impact vocational and higher education communities widely, as well as position Norway at the forefront of research, teaching and learning innovations. The artefacts produced will be transferable to other learning/training environments and industries. Problem-solving competence and working collaboratively with others are associated with high-quality education; these skills are also critical in our daily lives and on larger societal and environmental scales. This project will generate knowledge useful in teaching young people or adults, beyond formal education, and address the HESI³ and UN's sustainable development goal 10.

Moreover, the TeamLearning project engages with educational and technological challenges that could facilitate context-sensitive innovation involving AI. The notion of augmenting educational decision-making through AI and data-intensive innovations is becoming important in education and other sectors [41]. In 2020, the Norwegian government released a report promoting AI use in industry and the public sector, including education, proposing various scenarios in which AI could offer benefits. It, however, emphasizes that besides access to good infrastructure and data, research and competence building are important to provide a starting point for increased innovation and value creation [32]. The report also highlights the role of educators in defining when and how machines may guide learning and decision processes in educational and work settings.

2.3 Communication and exploitation measures

The target audiences for TeamLearn are aligned to the project's envisioned impact. **Researchers** in various fields will benefit from new knowledge about multimodal data and its use for learning purposes, as well as sets of CPS indicators for further testing. **Practitioners** (i.e., teachers, pedagogical developers, leaders) and **students** will benefit learning scenarios, a digital solution, materials, instruments, and guidelines for teamwork and CPS. **Technology developers** will benefit from source code for computing low-level multimodal data.

The dissemination plan is detailed in the application form and reflects a multi-level approach. For **scientific dissemination**, we make use of our own and our collaborators' international research networks and national-level networks. This ensures that the project makes important contributions to relevant research fields. Dissemination to the scientific community will occur through high-quality *publications in journals*, a *special issue* and contributions to *international conferences* in several disciplines. We emphasise *co-publication* within the project team and with collaborating partners, with at least one article in *disciplinary journals* in medical, nursing and legal education. Within our existing network, we already initiated a *jointly-authored book* (Routledge) on collaborative learning using automated support and digital artefacts. *Popular science dissemination* will occur through a webpage, a podcast, and media and social media presence. For **educational practice dissemination**, we will deliver (1) *learning designs* and *guidelines* for implementation in higher education programmes at partner institutions; (2) an English-language *mini-MOOC* providing knowledge and exercises for practitioners; (3) *open-access resources* with descriptions of the tool, sets of CPS indicators and learning designs for broad use; (4) *seminars* (with LINK) for faculty and programme leaders about outcomes to be used in university pedagogy courses and pedagogical development projects; (4) a *national conference* targeting institutional and educational leaders and relevant actors involved in workplace learning; (5) *articles* in science popularisation and sector outlets, as well as regular posting on professional networks.

³ <https://sustainabledevelopment.un.org/partnerships/hesi>

3 Implementation

3.1 Project manager

The project's principal investigator is Assoc. Prof. **Crina Damşa**, an experienced researcher in the area of higher education, studying group-based learning, educational design and digital teaching. Damşa participated in various research projects, leading work packages and empirical studies, and is currently leading one of EARLI's Center of Excellence in Research (E-CER)⁴. Damşa has varied research leadership experience in national and international project contexts, scientific associations and networks (see CV). Besides her research appointment, Damşa is affiliated to *LINK- Centre for Learning, Innovation & Academic Development*, where she consults faculty and leadership on pedagogical innovation, having thus an excellent opportunity for dissemination and exploitation of project outcomes.

3.2 Project team

The project team gathers interdisciplinary expertise from education, computer and communication sciences, learning analytics, healthcare and legal education, and design and innovation. All project partners and participants are presented below; name initials are used in Figure 3 to indicate assigned responsibilities.

IPED team. The team members at the hosting Department of Education (IPED) is composed of experienced researcher and junior researchers. **Damşa** (PID) leads the project, overall empirical work, data analysis, dissemination work and participates in co-design. Prof. **Åsa Makitalo** (ÅM), an expert in workplace learning, technology and expertise in professions, participates in the design of CPS indicators, empirical studies and analysis of interaction data. Dr. **Ole Smørdal** (OS), a computer scientist and currently leader of EngageLab, contributes to co-design and trials of the MAD. One **Postdoc** (PD1) organizes the co-design work and empirical studies, and assists with project coordination. One **PhD candidate** (PhD) conducts empirical work in Case 2; supervisors will be Damşa and Makitalo. One **research assistant** (A) assists data collection and management. A **developer** (D) from *EngageLab* contributes technical work on MAD with Monash University.

LINK is in contact with all Faculties and Departments at UiO, offering courses and pedagogical guidance. Through PID's and Mirjana Coh-Horvath's affiliation, LINK will facilitate dissemination among various users.

Co-researching partners. Three Norwegian *institutional partners* participate in a double role: they provide empirical contexts for the design experiment study, and participate in design and research. *Faculty of Medicine, Institute of Health and Society* at UiO provides Case 1. Prof. **Anne Moen** (AM), with expertise in co-design and technology implementation in healthcare education, and director of eColab, leads Case 1 and co-researches. Hilde Wøien (HW) and the Sampraks team conduct team training and participate in co-design of learning scenarios. *USN's Institute for Nursing and Healthcare* provide Case 2. Assoc Prof. **Lena Heyn** (LH) leads the case. LH and Prof. Hilde Eide (HE) are both experts on clinical communication and participate in co-design and empirical studies. *CELL Centre of Excellence at the Faculty of Law at UiO* is innovating the 5-years Master of Laws programme. Prof. **Malcom Langford** (ML), leader of CELL, leads and co-researches in Case 3. A lecturer and a pedagogical developer (Ped) participate in co-design and training in Case 3.

International partners: *Monash University, Australia* participates as full partner. Dr. **Roberto Martinez-Maldonado** (RMM) is a computer scientist, with expertise in learning analytics and modeling. He leads co-design and adaptation of the MAD, and quantitative multimodal data analysis. Prof. **Dragan Gašević** (DG), Director of the Centre for Learning Analytics and leading expert on learning analytics, advises on multimodal analytics solution and analysis. One **Postdoc** (PD2) participates in MAD adaptations and user trials. Dr. **Brendan Eagan** (BE), from *University of Wisconsin (USA)* has expertise in Epistemic Network Analysis. Eagan contributes the ENA and integration of interpretation on multimodal and qualitative data.

International participants. Prof. **Hanni Muukkonen** (University of Oulu, FI) has expertise on technology-enhanced learning and survey studies in higher education, and contributes to the analysis of quantitative data. **Assoc. prof Jeroen Jansen** (JJ) and **Assist. Prof. Anouschka van Leeuwen** (AvL) (Utrecht University, NL) have combined expertise in statistical analysis of group interactions, and use of learning analytics in teaching and learning. They participate in data co-analysis through project meetings and ongoing remote discussions.

Scientific advisory group. The project will have an international, interdisciplinary scientific advisory group. Prof. **Sten Ludvigsen** (IPED, UiO) is an expert in research on collaborative learning and analysis of interaction and advises on research design and integrative analytical approaches. Prof. **David Williamson Shaffer** (University of Wisconsin–Madison, USA), leading expert in quantitative ethnography and Director of the Epistemic Network Lab, advise on ENA and integrated interpretations. Assoc. Prof. **Alyssa Wise**, leader of New York University's Learning Analytics Research Network and expert in design of learning analytics systems, advises on modeling and work with multimodal data. Prof. **Davinia Hernandez-Leo** (University of

⁴ <https://earli.org/ECER>

Pamplona, Spain) is expert in learning design technologies, CSCL, data analytics, and architectures and devices for learning, and advises on co-design of MAD. **Dr. Klas Karlgren** (Karolinska Institute, Sweden), an expert in interaction design and interventions in medical and healthcare, advises on implementation.

2.1 Project organisation and management

The project is organized according to the **four phases** (see description in section 1.3 and Figure 3). The phases serve as organisational unit, resembling organisation through work packages.

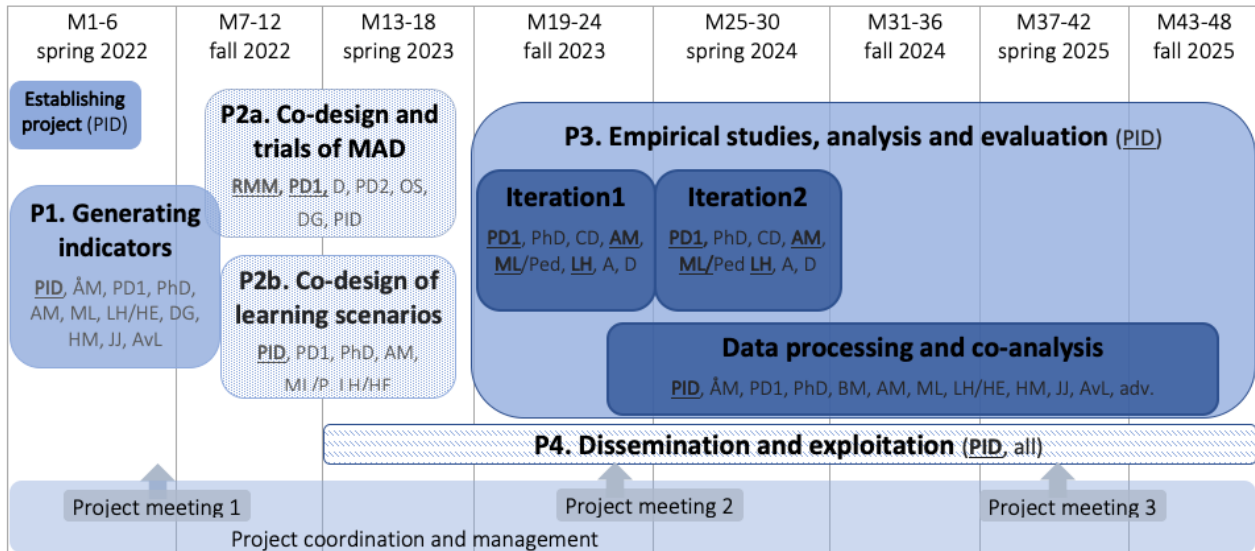


Figure 3. Project phases and activities. Project members indicated with name initials (s.2.2), leading members are underlined.

In the first four project months, PID organizes the personnel aspects, the planning of postdoc and PhD projects and the collaboration with partners. In *Phase1*, empirical explorations and generation of indicators are organized in parallel. PID and IPED-researchers conduct empirical work and co-design indicators in M4-8. Data is analysed by researchers for use indicators co-design. Case leaders and international collaborators also participate in co-design. *Phase2. Co-designand trials of MAD* involves RMM and PD1 as coordinators, with participation of the PID, EngageLab and Monash in M8-16. Case leaders assist trial work. Second activity in *Phase2. Co-design of learning scenarios* is coordinated by PID; with PD1, PhD, case leaders and other teachers participate in M10-16. The activities in *Phase3. Empirical studies, analysis and evaluation* are coordinated by the PID, with different members of the team assigned responsibilities and tasks. PID and Postdoc1 coordinates the data collection, in close collaboration with the case leaders AM, ML, and LH (M18-30). The PhD, Ped, D and A assist in data collection and management, and technical support. Data analysis is organized on continuous basis for PD1 and PhD; and in a) four remote data sessions together with international research partners, and 2) four meetings with local partners (M22-46). All project members participate in *Phase4. Dissemination and exploitation*. Partners contribute publications and dissemination at conferences and in own network; local partners disseminate outcomes and materials at own institutions; PID and LINK coordinate dissemination nationally. PID and PD1 ensure project management and coordination. *Three project meetings* will be organized, including all partners and Advisory group. *Work meetings* related to particular tasks and *data workshops* will be organized on needs-basis. The team management platform Slack will be used for collaboration, communication and information sharing among project members. The postdoc and PhD will be encouraged to have international collaborations/research stays (additional funding will be applied).

The project will benefit from an **advanced scientific and operational infrastructure**. It will be led by *Department of Education* at UiO, internationally recognized as research department and with a well-developed research administration and dissemination infrastructure. The key researchers are part of *HEDWORK*, a dynamic research group with a rich portfolio on higher education research. *EngageLab*, a research and technology development facility at IPED, provides the technical expertise for technology development and implementation. *eColab*⁵ provides facilities for team-based simulations. This is an excellent research and development environment for early career researchers, with opportunities to gain experience from collaborative research and local and international scientific networks. An aim of TeamLearn is to have gender balance, with currently a good balance between male and female members. The project will follow UiO's guidelines regarding new personnel to ensure gender balance and diversity.

⁵ <https://www.med.uio.no/helsam/tjenester/kunnskap/ecolab/>

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