Framework for Effective Teamwork Assessment in Collaborative Learning and Problem Solving

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Abstract. This paper presents an interactive team collaborative learning and problem-solving (ITCLP) framework for effective teamwork learning and assessment. Modeling the dynamics of a collaborative, networked system involving multimodal data presents many challenges. This framework incorporates an Artificial Intelligence (AI), a Machine Learning (ML) and computational psycho- metrics (CP) based methodology, system architecture, and algorithms to find pat- terns of learning, interactions, relationships, and effective teamwork assessment from a collaborative learning environment (CLE). Collaborative learning may take place in peer-to-peer or in large groups, to discuss concepts, or find solutions to real-time problems or working on situational judgement task (SJT). Intelligent Tutoring Systems (ITSs) have been mostly used as a supportive system for the varied needs of individual learners. The ITCLP framework enables development of ITSs for team tutoring and facilitates collaborative problem solving (CPS) by creating interactions between team members. Our team model maps team knowledge, skills, interactions, behaviors, and shared knowledge of team tasks, and performance. We will collect the team interaction log data, user eye tracking, and user portrait video/audio and will map team skills evidence based on CPS, a broad range of cross-cutting capabilities, which is part of an even broader Holistic Framework (HF) proposed by Camara and colleagues [1].

Keywords: Teamwork, Intelligent Tutoring Systems, Team Tutoring, Collaborative Learning, Collaborative Problem Solving, Machine Learning, Artificial Intelligence, Computational Psychometrics.

1 Introduction

Social structure and human connections impact our abilities as individuals, teams, and as communities to survive and prosper. Social and educational innovation is often a process of forming new social connections between teams, and the knowledge and re-sources they possess [2]. Team collaboration, simulations, audio-visual aids, interactive gaming, multi-sensory environments for capturing temporal inter-dynamics log-data and related technologies give us the capacity to provide learning opportunities in an extremely effective and efficient way. Such technologies and innovative instructional methods help to teach teams new concepts in novel ways and we believe that these

technologies will have a major impact on teaching (instructional team tutoring), learning and a successful workforce development [1, 3, 4].

A broad range of skills (e.g., creativity, communication, collaboration, problem solving) are increasingly required to succeed in the 21st century [5, 6, 7]. Measurement and training of such diverse skills present many unique challenges for assessment and learning, but it also creates fertile opportunities for research in the area [5, 6]. Collaborative learning and collaborative problem solving may take place in peer-to-peer situations, or in large teams, to discuss concepts, or find solutions to real-time problems. Modeling the dynamics of such a collaborative, networked system involving multimodal data (chat logs, game logs, audio/video, sensor input, behavioral expressions, eye tracking, actions and movement data) presents significant challenges. Our ITCLP framework ad- dresses many of them.

This paper focuses on an interactive team collaborative learning and problem-solving (ITCLP) framework to promote understanding of the behavior, group dynamics, task interdependencies and interactions within a collaborative learning environment (CLE). We are extending the concept of embedding micro-instructional resources through the Army Research Lab (ARL)'s Generalized Intelligent Framework for Tutoring (GIFT) [8, 9] or OpenEd [10] for CPS *Skill Up* activity into the ITCLP framework which will serve as the team Intelligent Tutoring System (ITS) module. OpenEd [10] is a learning objective repository (LOR), an online collection of educational resources, including open source foundational item sets, quizzes, videos, homework study references aligned with the Common Core and numerous other standards.

The ITCLP framework will explore the feasibility and validity of measuring evidence within team CLEs including: CPS Gamified assessments (i.e. ACT 'Circuit Runner' that can measure CPS facet abilities as participants seek to solve challenges presented within the game [11, 12]), social emotional learning (SEL) assessments (i.e. ACT Tessera [13]) and classic SJTs (i.e. Army combat operations). Our study will try to find a solution for a broad range of research questions such as, to what extent will CPS Gamified assessments provide valid and reliable data on a broad range of team-work CPS sub-skills and team competencies; what are the relationships (correlations) between CPS sub-skills as measured by CPS Gamified assessment and more traditional CPS assessment instruments (SJTs, self-report questionnaires).

The paper is structured as follows: the next section describes relevant work in the area of ITS approaches for team learning and related performance assessments. The third section discusses team skill measurement and how they are derived from the ACT Holistic Framework knowledge base. The fourth section of this paper describes different modules of ITCLP framework and how each module contributes towards collaborative learning and teamwork skill assessment. Finally, we end with a discussion of the ITCLP framework and future work.

2 Related Work

Over the years, ITSs have been successfully implemented for individual tutoring but very few efforts have been made for adapting this concept for team tutoring. Here we

briefly summarize some of the recent and most prominent work related to ITS implementation for collaborative learning and problem solving in a team setting.

The GIFT framework was developed by the Army Research Lab (ARL), for facilitating intelligent tutoring, which has four main service modules, including a learner module (supports adaptive learning), a pedagogical (instructional) module, a behavior module, and a domain module to provision training [8, 9].

Fletcher et al [14] in their work described the adaptation of the GIFT framework in a team setting and related states, and also discussed ITSs, shared mental models, and teamwork. They deliberated how the GIFT framework advances team learning by taking advantage of ITSs that interconnect to both individual and shared mental models. However, the GIFT framework lacks modules that are team centric and it also does not include models for capturing dynamic team interactions.

Assessment of team and task skills are difficult. Gilbert et al [15] in their recent article proposed a method for facilitating the authoring procedure for team tutors. In their work they used the GIFT framework for providing team tutoring and presented a demo of a military surveillance situation for two team members.

Cooke et al [16] highlighted the importance of the cognitive underpinnings of team performance in measuring team knowledge. Their research observed that cross-training was useful for measuring team knowledge which was based on the type of task work and prior team knowledge. The research found that these factors are important for improving team performance and to achieving desirable outcomes [16].

Graesser et al [17] offered an ITS based framework named 'AutoTutor,' which demonstrated learner-agent interactions in a natural language (a conversation between the two computer agents and the human learner). This framework also considered the learners cognitive and emotional state while interacting with the computer agent.

Rosen [18] presented an extensive effort on computer-based assessment of collaborative skills for exploring the feasibility of a Human-to-Agent (HA) approach. His findings indicated that CPS with a computer agent significantly helps in identifying higher levels of shared understanding, monitoring learner progress, and providing effective feedback.

Sottilare et al [19] illustrated a correlation between team behaviors and successful team learning and relative performance through adaptive instruction directed by an ITS. These finding allowed for the expansion and modification of teamwork models in ITS design.

Most recently Chopade et al [20] introduced the Competency Architecture for Learning in teaMs (CALM) framework, an extension of the GIFT framework for modeling dynamic team interactions for intelligent tutoring. In their work they presented a novel method by incorporating CPS skills along with feedback based on advanced AI-ML to track dynamic team interactions and provide personalization, and performance visualization. They presented several ITS methodologies to model team performance, as well as individual performance of the team members.

The next section describes the knowledge base for teamwork skills, and CPS functional attributes assessment.

3 Teamwork Skill Measurement

The ACT Holistic Framework (HF) [1] provides a comprehensive mapping of the knowledge and skills needed for education and workplace success. The Holistic Framework includes 4 broad domains: a) Core academic skills (e.g., mathematics, science, and English Language Arts), b) Cross-cutting capabilities (e.g., CPS, critical thinking, information technology (ICT) skills, learning skills), c) Behavioral skills (e.g., dependability, teamwork, stress management), and d) Education and career navigation skills (e.g., self-knowledge, interests, values) [1]. The Behavior framework also includes skills such as, the Sustaining Effort, Keeping an Open Mind, and Getting Along with Others dimensions [1, 7].

A broad range of skills (e.g., creativity, communication, collaboration, and problem solving) are required to thrive in rich, modern societies: we need effective, creative knowledge seekers and collaborative problem solvers. Our ITCLP framework focuses on CPS—part of the HF which outlines the skills required to effectively combine problem solving, communication, and behavioral strategies to successfully solve a problem within a team context. At the same time, assessment of these constructs through traditional means has been difficult [5, 6]. This study explores the assessment of these con- structs through different modalities like playing a game, SJTs, or answering survey questions.

The collaborative problem-solving construct under investigation can be broadly segmented into two components - Team Effectiveness, and Task Effectiveness. These two distinct components are key to the maximal collaboration within a group. For example, if a team does not get along well, but still completes the task, there may be a better possible outcome. Conversely, if the team does get along, however fails to complete the task, the outcome again is not ideal.

These two broad components are further broken down into five functional categories (ten sub-categories), which enables more specific analytical evaluation of the team's behavior and outputs. For the purposes of this study, we plan to extract evidence of these categories from participant discourse, as well as telemetry within the context of a virtual space. These two components include broad CPS functional sub-categories (inclusiveness; clarity; commitment; communication; contextualization; goal orientation; strategy; execution; monitoring and evaluating).

Examples of this evidence vary based on the category, but all categories have evidence that is accessible from chat logs, audio and video data collection. For example, Clarity can be evaluated based on the number of clarifying questions that are asked during the session, and Strategy can be evaluated based on conversations relating to the information necessary to resolve the task.

The collection and analysis of this data in real time requires an integrated experience that seamlessly captures the data and updates models of user ability to support in vivo enrichment. In next section we introduce the ITCLP framework for measurement and effective assessment of the teamwork skills discussed in this section.

4 Interactive Team Collaborative Learning and Problem-Solving Framework (ITCLP)

This section describes the ITCLP framework. Figure 1 shows the basic ITCLP frame-work block representation: knowledge base (Domain model); Collaborative learning (Learning model); Task/Action, CPS, Team Competency model; AI-ML Computational Psychometrics (CP) module, Evidence-response module; Report assessment module; Team ITS and instructional model. The basic ITCLP framework presents techniques for modeling a networked system using multimodal data, relying in AI-ML, and CP. This framework addresses the complexity of team tutoring, as well as integrates framework modules into an ITS such as GIFT. Connectivity and information flow between these modules are incorporated and discussed in Figure 2. In Figure 2 we describe ITCLP framework in detail with different functional modules. This figure describes structure and function of different modules and their connectivity to facilitate collaborative learning and CPS teamwork skill assessment. Here we discuss different modules in Figure 2.

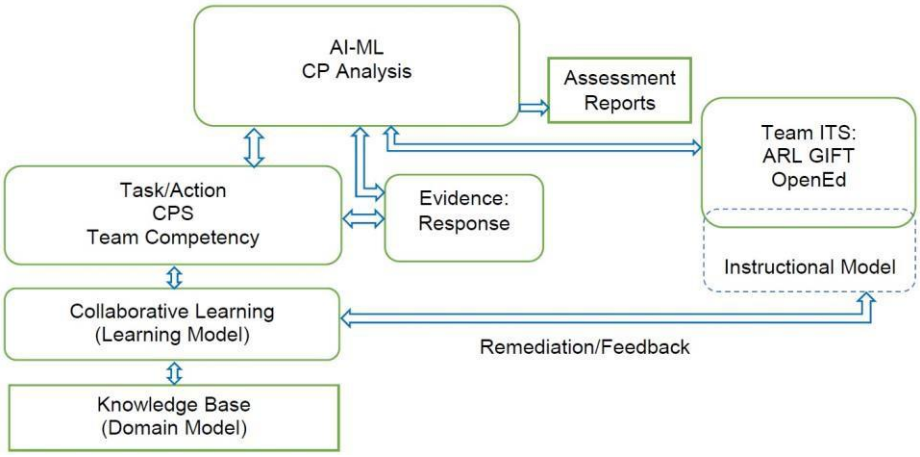

Fig. 1. Basic Interactive Team Collaborative Learning and Problem-Solving Framework (ITCLP) block representation.

ACT Holistic Framework (see Figure 2A): As discussed in section three, this is the knowledge base unit of the ITCLP framework. The behaviors and skills necessary to competently solve complex problems, communication, and interactive strategies to successfully handle the situations within a team context are outlined in ACT's CPS con-struct, within the HF.

Collaboration Skill mapping (see Figure 2; module B): Collaborative Problem Solving (CPS) is one of the primary constructs within the Cross-cutting Capabilities domain of the HF and incorporates both the behavioral skills and thinking skills required to effectively solve a problem as a group. While the academic components of the framework have well established instruments for measuring skill evidence, areas such as CPS present challenges to researchers for gathering reliable, viable assessment results.

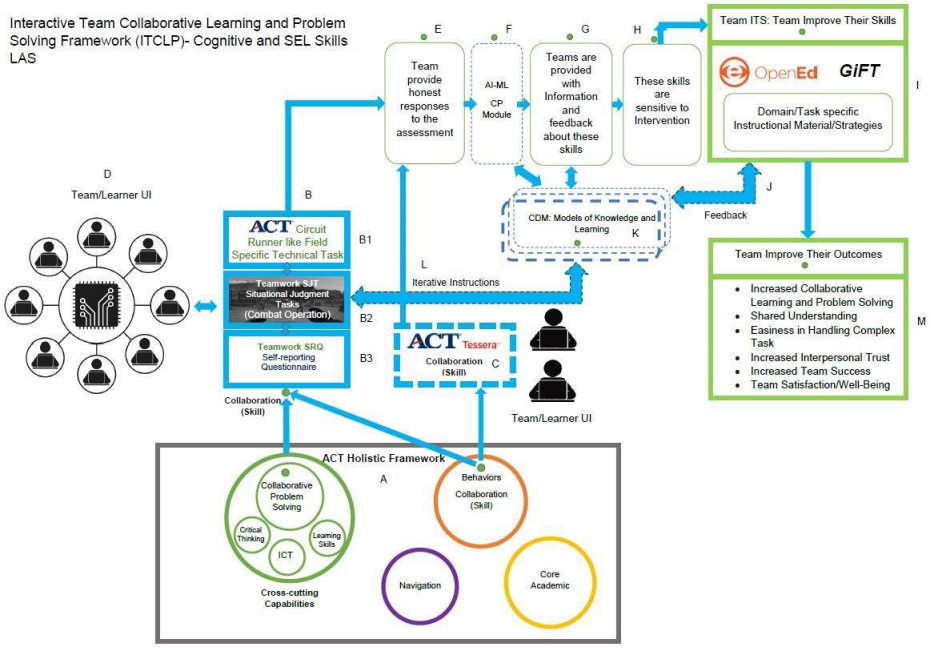

Fig. 2. Interactive Team Collaborative Learning and Problem-Solving Framework (ITCLP) - Cognitive and SEL skills learning and assessment (LAS).

ACT Circuit Runner - (Module like field specific technical task (see Figure 2; module B1): ACT collaborated with Digital Artefacts (DA) to build an online, human-agent, CPS video game called "Circuit Runner" that features a first-person 3D perspective as a player navigates a series of rooms/hallways in a maze [11, 12]. The rooms have challenges for the player to solve to proceed and ultimately complete the game. The participant is required to collaborate with a virtual agent using a set of scripted dialog elements shown in Figure 3. The dialog trees were designed to align with the HF CPS construct in order to elicit skill evidence with a range of performance level options per facet. In solving the challenges, the participant must collaborate with a virtual agent via a chat console interface shown in Figure 3. The dialog tree responses are tagged as providing evidence of collaborative problem solving (CPS) subskills at various performance levels [11, 12]. The goal of the research behind it is to analyze the ability for the game to measure the behavior skills and thinking skills that support the team effectiveness and task effectiveness components of CPS. CPS components includes: inclusiveness, role and goal clarity, communication, team and goal commitment, problem and problem space con- textualization, goal orientation, strategy, execution, monitoring and evaluating. For team settings, we will use other field specific task like CPS circuit runner for a teamto perform, through which we will measure CPS skillsets.

Fig. 3. CPS "Circuit Runner" game modules-user interface and conversation flow (CF).

CPS Situational Judgement Task like Combat operation (see Figure 2; module B2): A situational judgment task (SJT) is one in which teams are exposed to or asked to, respond in a given situation. Situations can be described using text or through audio or video, and response types used, can include multiple choice, ordered multiple choice, constructed response, and ratings among others [21, 22]. SJTs may be developed to replicate more intelligent and complex judgment processes (as in a scenario similar to the Army Combat operation) than are possible with conventional assessments. The task-based methodology allows the assessment of team member attributes, including attitudes, sense of belonging, leadership, teamwork, achievement orientation, self-reliance, dependability, and conscientiousness (each task/test includes few items per attributes) (e.g., [22, 23, 24, 25, 26]). Other related modules developed by ACT include the WorkKeys for team- work assessment. In the current ACT SJT module, attributes are aligned with the CPS construct and three CPS sub-skills are used for team skill testing: Perspective Taking (PT), Establishing Strategy (S), and Problem Feature Analysis (PFA).

CPS Self-reporting questionnaire (see Figure 2; module B3): Through this instrument, team will report on a 1-10 Likert scale (1-Not at all; 10-To a Large Extent/Excellent) their competence level in CPS. Based on prior Programme for International Student Assessment (PISA) studies [5, 6] some of the sample items are adopted which include: Detecting gaps in shared understanding in a team task; Identifying strengths of teammates; Delegating tasks to others to accomplish team goals; Individual team member's ability to competently lead the team. For data collection, ITCLP framework also includes additional instruments 'HEXACO Personality Assessment' for measuring skills such as Honesty/Humility (HH), Extraversion (Ex), Emotionality (Em), Openness (O), Agreeableness (A), Conscientiousness (C), and Altruism (Alt).

ACT Tessera (see Fig. 2 C): ACT has also developed another instrument called 'Tessera' for social emotional learning (SEL) that measures five evidence-based skills- Responsibility/Grit- Conscientiousness (two conscientiousness scales are combined for new version), Teamwork/Cooperation- Agreeableness; Composure/Resilience-Emotional Stability; Curiosity/Ingenuity- Openness; Leadership/Communication Style-Extraversion [13]. ACT has developed the "Tessera," instrument to evaluate SEL so we used "Tessera," instead of using other instruments that measure emotional

and social intelligence. Some of the tasks of this planned research will include collection/measurement of teamwork interaction data as shown in Table 1 using instruments discussed above and shown in Figure 2, modules B and C. It is anticipated that there will be extensive work in order to collect the data needed for the analysis.

Table 1.

Teamwork Interaction Data

Type of Data	Attributes of Data
Reported Data	age, gender, technology use, personality facets, etc.
Task specific/Action oriented (In-game) Data	Chat logs (Conversation flow); Audio/Video; Game Logs; Behavioral expressions; Eye Tracking; Time- In-game & Between Game; Object clicks.
SJT Data	30 question multiple-choice selection of leveled responses aligned with sub-skill levels.
HEXACO Data	100 question measure of the six major dimensions of personality.
Tessera Data	Responses from multiple-choice selection aligned with five skills.

Team/Learner User Interface (UI) (see Figure 2; module D): Through this module the team interacts with the readable/understandable tasks, actions/inputs and receives actionable feedback or output. The UI appears in various platforms, modes, and it will go beyond mere reporting to include new information and perspectives on what an individual might explore or do next. These modules keep teams engaged and monitors continuous team interactions. Team response (see Figure 2; module E) is a connected module to the team UI (Figure 2; module D). The team is able to provide honest responses to the task or to the assessment.

AI-ML Computational Psychometrics (CP) Module (see Figure 2; module F): ML module will analyze behavior and telemetry data from chat logs, game logs, behavioral expressions, eye-tracking, and motion sensors, for team learning analysis as shown in Figure 4. AI-ML modules will integrate techniques from Computational Psychometrics (CP), which is a new field of learning and assessment [27, 28, 29] and will utilize deep knowledge tracing (DKT) techniques such as a convolutional neural network (CNN) for feature extraction, skill identification and pattern recognition. Our study will incorporate machine learning algorithms such as k-means, Support Vector Machines (SVM), and Hidden Markov Models (HMM) for multimodal behavioral analysis and for feature extraction, clustering, and correlation analysis. We will attempt to build text based Natural Language Processing (NLP)/ ML models to identify or classify various values related to CPS subskills with chat logs (conversation flow) as the source of data from the study. The outcome for this model will represent a baseline for the preceding phases and potential studies to follow.

Team Feedback (see Figure 2; module G): This model is built on top of the models of knowledge and learning (cognitive diagnostic model Figure 2; module K). The team feedback model uses information provided by the models of knowledge and learning to provide team with actionable feedback. The feedback model provides individual member and team member with a *Skill Up* activity that would allow the team members to practice the skills they have yet to master. This work is built directly on the AI-ML, computational psychometric and statistical development of the knowledge and learning model and on the HF.

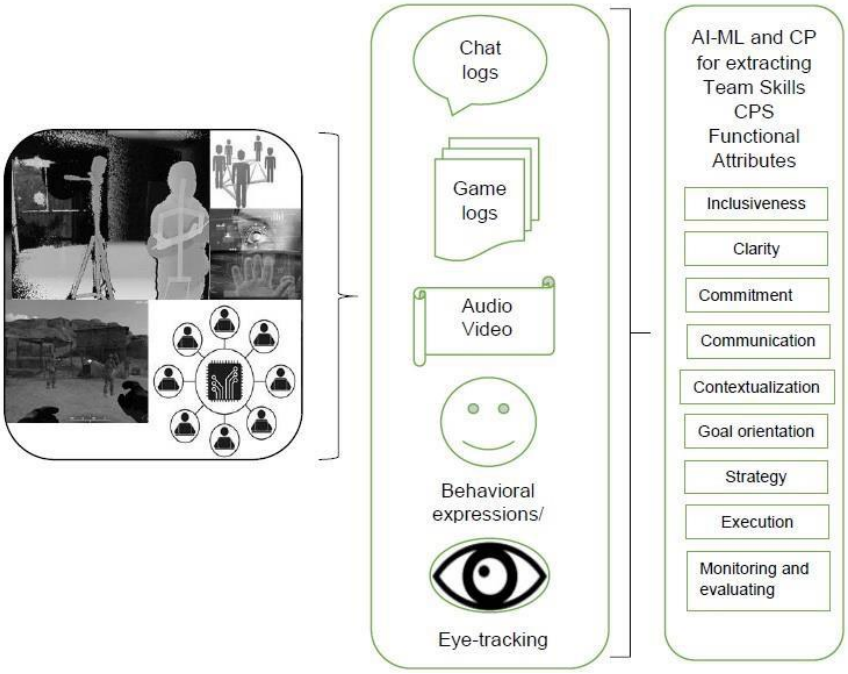

Fig. 4. AI-ML CP for multi-modal data analytics and for team skill assessments.

Intervention support (see Figure 2; module H): As described in above module (2 G), based on team task and related actions, team members are provided with actionable feedback. Since teamwork skills are sensitive to intervention, the system will provide strategic personalized responses to the team, and receptive to the needs of each team member along with deep intervention support. Our design includes intervention support for the entire team (meaning, messages are delivered to the entire team).

Team ITS (see Figure 2; module I): This module will function as a content authoring or team tutoring tool for providing domain/task specific instructional material/strategies. We will integrate a resource similar to OpenEd [10] /ARL GIFT [8, 9] for supporting team tutoring. Such resources will help the team to practice their skills for required improvement.

The OpenEd [10] resources are carefully tagged by curators with ACT HF skills to deliver value to learners seeking help, or for a *Skill Up*, or for tutoring activity. The *Skill Up* content is properly aligned and curated, and we can link the results of our feedback model to the appropriate resources. ITCLP framework is able to provide this level of integration and team interaction through a LOR like OpenEd. This module also includes a measurement backend designed to capture team interaction analytics, team state data and learning analytics (assessment and media events). We will curate team interaction data available for analysis and inclusion in the instructional module. Learners' activities will be exposed individually for different skills (deep linking into

various parts of the ITCLP activities). OpenEd resources are embedded using a combination of OpenEd application programming interfaces (APIs) and curation of resources aligned down to the strand level of the holistic framework. Other *Skill Up* category will be generated by the OpenEd content as events stream which is based on two different IMS Global Caliper sources: assessment (quiz) or media (video) events. These events will be connected to the data integration platform in order to enable access to the data generated by the teams while using the application. The feedback bridge module (see Figure 2; module J) act as mediator or as *Skill Up* bridge between team ITS module (Figure 2; module I) and modules of knowledge and learning (Figure 2; module K).

Models of Knowledge and Learning (see Figure 2; module K): Cognitive Diagnostic (CDMs) are models developed principally to identify the mastery, or deficiency of skills (or attributes) being measured in a specific domain. Models of knowledge and learning will provide cognitive diagnostic feedback about mastery or lack of skills based on specific team task or domain. Using our psychometric and statistical expertise alongside ML algorithms, we will build models of knowledge and learning for skill improvement and to create a personalized experience for learners. Once we add-on existing data about team's learning with the results of models of knowledge and learning, the feedback model will use that new information to provide the team with actionable instructions (see Figure 2; module L): i.e. iterative instructions about required actions or steps to follow (For teams' interaction through block 2B and 2C). This module will receive required instructions through team feedback module (2G) and the models of knowledge and learning (2K).

Team outcome (see Fig. 2 M): This module will present overall team performance (overall team activity/performance dashboard) and relative improvements in their abilities or skills such as increased collaborative learning and problem solving; shared understanding, ease in handling complex tasks, increased interpersonal trust, increased team success, team satisfaction/well-being. The team will also receive their relative performance through team/learner UI module.

This ITCLP framework provides a robust and flexible approach to both evaluation of team dynamics and delivery of content across a variety of task designs. Each component can be configured in various capacities to support real-time feedback, or after-action feedback depending on the needs of the user, and can incorporate prior knowledge that is available about each user. This architecture also very good for the incremental development of modules across many content domains and subjects.

5 Discussion and Future work

Modeling and assessment of teamwork skills are relatively complex tasks, but AI and ML based technological developments are helping the scientific and educational community to bridge this gap. Seamless assessment of evidence-based team tasks and team competency also adds another layer of computational challenges. The GIFT framework is promising for individual tutoring but has not yet been implemented for team tutoring.

The ITCLP framework presented in this paper aims to address these challenges by extending the GIFT framework for promoting feasibility of collaborative team learning (team tutoring) and measuring associated team skills and performance.

The ITCLP framework will provide shared mental models for effective team learning, will advance understanding of team behavior, group dynamics, and task interdependencies and will act as testbed for team training using learning object repositories or other GIFT-like resources. Our future work will aim toward development of a team-oriented CPS/Circuit Runner-like field specific technical task, a video-based SJT like Army combat operation, a self-report questionnaire and ACT Tessera-like SEL tools. Later work will focus on the development of team tutoring APIs through OpenEd and the integration with the GIFT framework.

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