Shih, J. L. et al. (Eds.) (2019). Proceedings of the 27th International Conference on Computers in Education.
Taiwan: Asia-Pacific Society for Computers in Education

How to Measure the Collaborative Problem-solving Competency Based on Conversational Agent

Ge Wang [a], Bian Wu [a*], Yiling Hu [a]
[a] *Department of Educational Information Technology, East China Normal University, China*
* bwu@deit.ecnu.edu.cn

Abstract: Nowadays, collaborative problem-solving competency has become one of the essential core skills for talents in the 21st century. Limited by the complex and variable factors of collaborative problem-solving activities, the current assessment method was difficult to understand the real situation of students' collaborative activities and problem-solving. Based on the PISA2015 collaborative problem-solving competency assessment framework, this study build an assessment model and integrated the computer conversational agent technology to develop the prototype of the collaborative problem-solving competency evaluation system. We found the performance level of individual and teams' collaborative problem-solving patterns. It provides a reference for the evaluation of collaborative problem-solving competency, and also provides a new direction for human-computer interaction based on conversational agents.

Keywords: Collaborative Problem-solving; Conversational Agent; Assessment Research

1. Introduction

With the development of modern society and the constant change of knowledge, the division of labor becomes more and more refined. Many projects need to be completed by people from different fields and majors through communication and collaboration. Nowadays, collaboration ability has become a necessary competency for talents with social competitiveness.

Collaborative problem-solving (CPS) competency as a composite skill of collaboration ability and problem-solving ability, its cultivation and evaluation have received extensive attention. UNESCO's report on "Learning: The Treasure Within" highlighted the importance of "teamwork competency" (Delors, 1998); The Singapore Ministry of Education (2017) added a "Project work" to the school curriculum, which clearly lists the four skills of knowledge application, communication, collaboration and independent learning as the learning outcomes; The 21st Century Skills Alliance defined problem-solving and collaboration as skills that every American teenager needs to learn at school (Voogt & Roblin, 2012).Scholars from various countries pay more attention to how to set the situation of CPS activities to cultivate students' CPS competency. However, in terms of assessment, it is limited by the variety and complexity of the influencing factors of CPS ability. It is difficult to measure the actual collaboration situation and problem-solving behavior in this environment. In fact, CPS skills are often seen as skills that are difficult to measure (Stecher & Hamilton, 2014). Collaborative activities and problem solving activities are non-linear sequence activities. It becomes a challenge to adopt an effective scheme to model and quantify this complex system.

2. Literature Review

2.1 Concept and Evaluation Framework of Collaborative Problem-solving

Related research on CPS stems from the social attributes of problem solving (Vygotskie, Embong, & Muslim, 1978) . The current accepted concept of CPS competency comes from the OECD's definition in PISA 2015 (OECD, 2017), "the capacity of an individual to effectively engage in a process whereby two or more agents attempt to solve a problem by sharing the understanding and effort required to come to a solution and pooling their knowledge, skills and efforts to reach that solution." The existing research on CPS has accumulated a lot of theoretical frameworks and models. Stevens and Campion (1994) proposed a teamwork conceptual framework that included five elements: conflict resolution, collaborative problem solving, communication, goal setting and performance management, planning and task collaboration. Griffin (2011) defined the ATC21S framework, which divided the CPS competency into two dimensions: social skills and cognitive skills. In 2017, the OECD released the PISA2015 Collaborative Problem solving Framework, which is a framework matrix consisting of three core social skills and four traditional personal problem-solving stages (OECD, 2017).The evaluation framework of this paper is based on the PISA2015 framework.

Table 1

Matrix of collaborative problem-solving skills for PISA 2015 (OECD, 2017).

	(1) Establishing and maintaining shared understanding	(2) Taking appropriate action to solve the probler	(3) Establishing and maintaining team organisation
(A) Exploring and understanding	(A1) Discovering perspectives and abilities of team members	(A2) Discovering the type of collaborative interaction to solve the problem, along with goals	(A3) Understanding roles to solve the problem
(B) Representing and formulating	(B1) Building a shared representation and negotiating the meaning of the problem (common ground)	(B2) Identifying and describing tasks to be completed	(B3) Describe roles and team organisation (communication protocol/rules of engagement)
(C) Planning and executing	(C1) Communicating with team members about the actions to be/being performed	(C2) Enacting plans	(C3) Following rules of engagement, (e.g. prompting other team members to perform their tasks)
(D) Monitoring and reflecting	(D1) Monitoring and repairing the shared understanding	(D2) Monitoring results of actions and evaluating success in solving the problem	(D3) Monitoring, providing feedback and adapting the team organisation and roles

2.2 Conversational Agent

In CPS activities, collaborative problem solving competency are susceptible to a variety of factors, such as situational complexity, partner behavior, and so on. The human-computer interaction evaluation model based on conversational agent can be used to reduce the impact of uncertainty factors. The conversational agent combines computer and conversations to collect log data through a broader interaction with the individual or meaning, and is able to assess the individual's ability to acquire knowledge, skills, and language at the cognitive and non-cognitive levels (Jackson & Zapata, 2015). Compared with the traditional evaluation methods, the human-computer interaction evaluation mode makes the performance of individual ability more stable(Graesser, Chipman, Haynes, & Olney, 2005). On the whole, conversational agent technology can provide evidence and help for formative assessment of CPS competency assessment.
To this end, this study aims to answer the following research questions:
Research question 1: how to design conversational agent to simulate real collaborative problem-solving?
Research question 2: how to measure collaborative problem-solving competency based on conversational agent?

3. Model Design

3.1 Evaluation model

PISA2015 provides individuals with complex task situations and further tests their CPS ability, which involves not only the reasoning process of the tested individuals in the problem situation, but also their communication, management and social process in the collaborative environment. Based on the research of collaborative problem solving, we proposes the following evaluation framework, as shown in Figure 1.

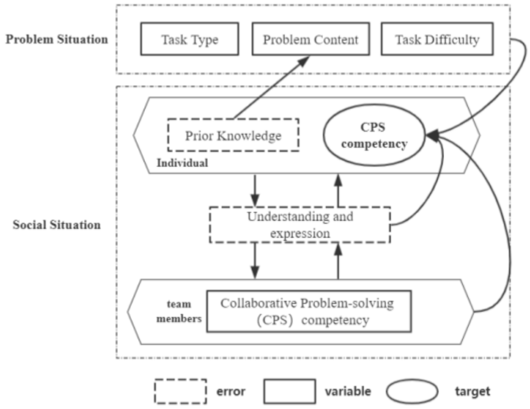


Figure 1. Evaluation Framework of CPS Competency

the CPS evaluation framework should consist of two parts: the problem situation and the social situation.The problem situation includes three variables, task type, problem content, and task difficulty. (1) Task type: It determines the ability tendency of individual in the current problem situation. (2) Problem content: It determines the limitation of the ability to examine the current situation, including content-related problem and content-independent problem. (3) Task difficulty: It is the comprehensive evaluation result of the task. In social situation， Individual CPS skill is influenced by other members of team. we can simply divide them into: external self-expression and individual acceptance to understand the expression of others.

3.2 Logic Design and Architecture Design of Conversational Agent

Figure 2 shows the architectural design of the Collaborative Problem Solving Supported Conversational Agent (CP2SCA). Which aims to simulate the collaborative performance of the tested individuals in the real problem situation with other members of the team by embedding the dialogue manager module.

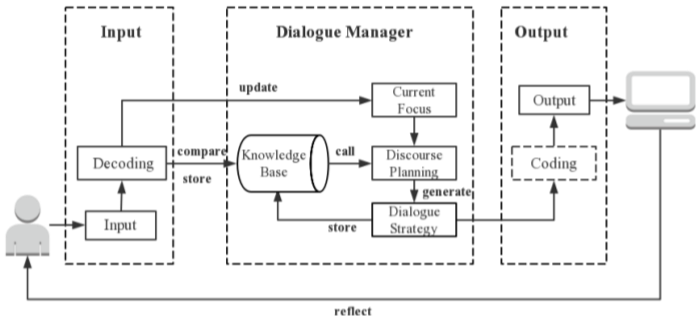


Figure 2. Architecture of Collaborative Problem Solving Supported Conversational Agent (CP2SCA)

The logic of the CP2SCA is: First, when the user inputs the information, the system decodes the input content, stores it into the database, and records the decoded content into the current focus module, updating current problem solving state of user utterance content, implements the tracking of the conversation state. Then, the conversational agent completes the planning of the discourse according to the current focus, the record of the existing information of the database and the input content, and formulates a suitable dialogue strategy coding scheme. Finally, the dialogue strategy is coded as the language of human-computer communication, and the output is the reflection content of the agent to the user.

4. Method

4.1 Experimental Tool Design

In addition to the basic user information collection functions (login interface and task information introduction page), the system focuses on the CPS activities. The main interface and functions are shown below: The system includes three interfaces: experimental control, chat dialogue, and history record. Experimental control is the main operational interface of the system, as shown in Figure 3a. Chat dialogue is a dialogue communication interface between the subject and the conversational agent.(Figure 3b). The history interface (Figure 3c) stores all the experimental and conversation records of the subject and the agent. The subject can view the experimental records on the interface, or forward them to the conversational agent companion to change the current focus status of the team discussion.

The problem situation set by the assessment system is "Exploration of New Species": the scientific laboratory has collected samples of unknown attributes. Participant should cooperate with colleagues (conversational agent), the experimental exploration is carried out, and finally the characteristics of "unknown samples" need to be clarified. During the experiment, the system will collect the number of discourse rounds (number of discourse sets), dialogue rounds (number of statements), step size (number of individual speeches and mouse clicks), performance (number of correct conclusions), etc.

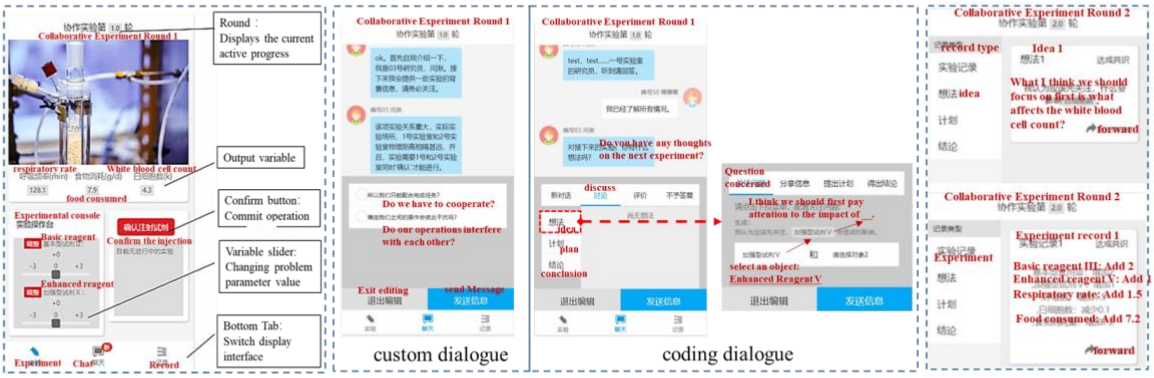


Figure 3. (a) Experimental Control Interface. (b) Chat Dialogue Interface . (c) History Record Interface

4.2 Participant and Process

Since the CPS competency is an indispensable ability for a individual to enter the society from the school, he participants of the experiment are 30 graduating students from a university in East China, aged between 24 and 26. Participants completed CPS tasks by collaborating with the conversational agent in the test environment. Then they filled the survey, which included the technical acceptance scale and open questions.

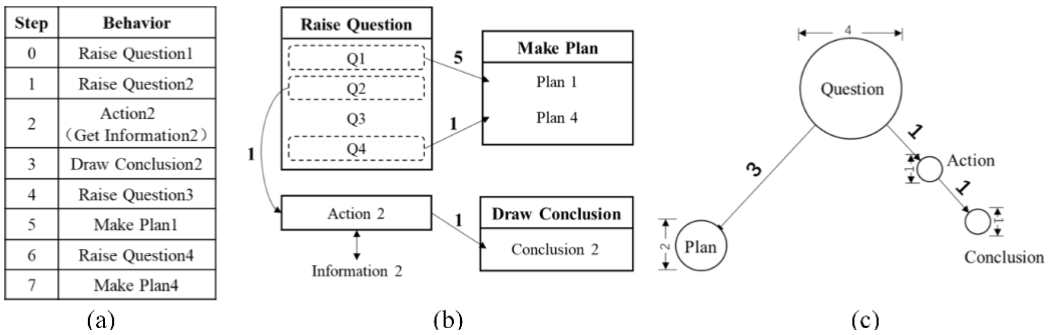
5. Result

5.1 Validity Test of Prototype Tools

The results show that the technical acceptance is M = 5.55, SD = 0.78. It can be seen that the technical acceptance of the evaluation system is higher. The answer to the open question indicates that participants generally have a higher degree of recognition of the prototype tool. As a result, prototyping tools can basically simulate real-world CPS activities and provide users with basic interactions for self-expression.

5.2 Analysis of CPS Behavior Characteristics

Behavioral characteristics describe the behavioral sequence preferences exhibited by individuals in the process of collaborative problem-solving activities, while the behavioral characteristics exhibited in individual collaborative problem-solving activities have not been standardized. According to the characteristics of its sequence, We can use the number of rules explored in each stage and the dialogue rounds between stages to construct a directed graph, where the output behavior is nodes and the feedback behavior is steps. It can integrate nonlinear and unstructured process data into an intuitive structured model.



Step	Behavior
0	Raise Question1
1	Raise Question2
2	Action2 (Get Information2)
3	Draw Conclusion2
4	Raise Question3
5	Make Plan1
6	Raise Question4
7	Make Plan4

Figure 4. (a) Unstructured Team Behavior Data. (b) Unstructured Data Collation *(Note: The number marked between the behaviors is the step size)*. (c) Directed Graph of Team Behavior Characteristics

For example, the non-structural data of team behavior collected by the system is shown in Figure 4a. The data is classified according to the four stages of problem solving to obtain Figure 4b. The step size between the stages is the interval value of the number of steps involved. Since the relationship is complicated and difficult to express, it can be simplified by the directed graph shown in Figure 4c. The radius of the circle is the total number of consensus reached at this stage; the length of the line is the average step size, and when there are multiple lines of different step length between the two elements, the mean value is taken.

5.2.1 Analysis of Individual Behavior Patterns

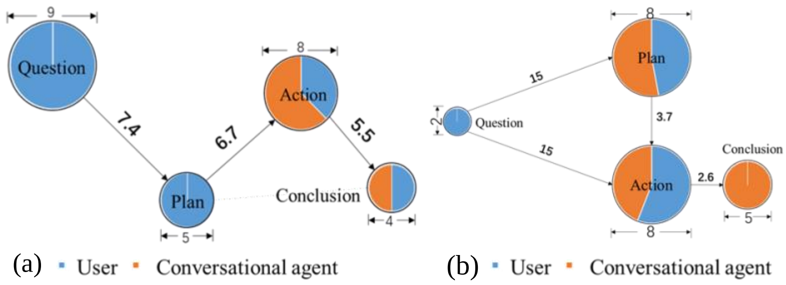


Figure 5. (a)Team09 (b)Team02 behavior characteristics and individual contribution

According to the proportion of individual output behavior in the teamwork CPS behavior, we can visually see the team's CPS behavior characteristics, as well as the individual's contribution in each stage of CPS, and understand the individual's behavior in the group CPS process. Taking sample 09 and sample 02 as an example, a graph of individual output behavior characteristics generated by adding a pie chart to a directed graph is shown below.

From the perspective of individual contribution of sample 09, the contribution output of participant 09 is 100% in the proposed stage and the planning stage. All questions and plans are formulated by the participant. There is no collaboration in these two phases. In the Action phase, five of the eight operations followed the plan, three were unplanned. In the conclusion phase, the participant‘s contribution rate is 50%. Participant 02 is dominant in the Question stage. During the Plan and Action stage, the contributions of the participant and the conversational agent are more balanced, but the final conclusions are all summarized by the conversational agent.

On the whole, participant 09 had a strong sense of leadership in the CPS process, but his ability to execute was not good, and he was not good at following plans. He need further develop his ability to collaborate with others. Participant 02 is more inclined to the role of leader in the CPS processHis ability to execute is quite good, but his ability to summarize is not strong. His team collaboration ability is strong, but problem-solving ability is slightly weaker.

5.2.2 Analysis of Team Behavior Patterns

Combined with the established CPS characterization model, we found two behavioral patterns that emerged from the team in CPS activities: problem thinking and plan making.

Teams with problem-thinking behavior pattern, their CPS path starts from the question stage, and externalizes the thinking at the Question stage. The team's thinking is active, and it is possible to consider many questions based on the task requirements, and then make plans to draw conclusions. Due to the large number of questions, it is easy to appear in the CPS activities that the plans are difficult to correspond to the questions one by one. As shown in Figure 5a, Team 09 has a much smaller number of plans than the number of questions raised. They are not effective problem-solving behaviors. At the same time, the step length between the question stage and the plan stage is the largest (7.4). It can be found that the team consumes more dialogue communication between the analysis of the task requirements and the development of the corresponding plan. Teams with planned behavior patterns, their CPS path starts from the plan stage, and the thinking externalization is shared with people in the plan stage. In the question stage, the team's thinking is not divergent, but it is better at turning questions into more specific plans, making plans more enforceable. Therefore, the number of plans making based on the questions is much larger than the number of questions. Compared to the problem-thinking pattern, the lines between the “plan-action-conclusion” are shorter and the connections between the three are closer.

6. Conclusion

The study proposes an assessment framework for CPS competency. Based on the existing concept of dialogue management, we developed a CPS competency assessment system, which can simulate the real CPS situation. We design a context-based computer conversational agent to encode unstructured discourse into structured data to achieve "human-machine dialogue". The conversational agent collects procedural data when collaborating with individuals to complete tasks. By visualizing the process data, we can clearly understand the behavioral characteristics of individuals and teams. We can develop evidence-based strategies to improve individual CPS competency. The system simplifies the assessment method, ensures the feasibility of technical application, and the standardized CPS process analysis model has certain promotion value.

7. References

Delors, J. (1998). *Learning: The treasure within*. Unesco.

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS quarterly*, 319-340.

Graesser, A. C., Chipman, P., Haynes, B. C., & Olney, A. (2005). AutoTutor: An intelligent tutoring system with mixed-initiative dialogue. *IEEE Transactions on Education*, *48*(4), 612-618.

Griffin, P., & Care, E. (2015). The ATC21S method. In *Assessment and teaching of 21st Century Skills* (pp. 3-33). Springer, Dordrecht.

Jackson, G. T., & Zapata-Rivera, D. (2015). Conversation-based assessment. *R&D Connections*, *25*, 1-8.

OECD (2017), *PISA 2015 Assessment and Analytical Framework: Science, Reading, Mathematic, Financial Literacy and Collaborative Problem Solving*, PISA, OECD Publishing, Paris, https://doi.org/10.1787/9789264281820-en.

Singapore Ministry of Education (MOE). (2017). Retrieved May 12, 2019, from: https://www.moe.gov.sg/education/programmes/project-work

Stecher, B. M., & Hamilton, L. S. (2014). *Measuring Hard-to-Measure Student Competencies: A Research and Development Plan. Research Report*. RAND Corporation. PO Box 2138, Santa Monica, CA 90407-2138.

Stevens, M. J., & Campion, M. A. (1994). The knowledge, skill, and ability requirements for teamwork: Implications for human resource management. *Journal of management*, *20*(2), 503-530.

Voogt, J., & Roblin, N. P. (2012). A comparative analysis of international frameworks for 21st century competences: Implications for national curriculum policies. *Journal of curriculum studies*, *44*(3), 299-321.

Vygotskie, L., Embong, A. R., & Muslim, N. (1978). Mind in society: The development of higher psychological. *info: Cambridge: Harvard University Press, 1978*.