Analysis and Improvement of Classroom Teaching Based on Artificial Intelligence

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1 Introduction

The classroom is the core environment for teaching and learning and provides a complex, multielement interwoven real situation. Classroom teaching plays an important role for achieving high-quality education. Thus, many scholars have put efforts into classroom teaching analysis and efforts for improvements employing quantitative and qualitative methods since the last century (Jacobs et al. 1999). For example, the quantitative analysis such as Student-Teacher analysis method (Cheng et al. 2018) and Flanders Interaction Analysis System (FIAS; Flanders 1963) are based on time-coding analysis. The qualitative analysis is mainly reflected in the analysis of teaching activities and the content of courses (Hatun Ataş and Delialioğlu 2018).

However, common classroom teaching analysis, which is based on coding and counting behaviors and discourse interactions between teacher and students, has been criticized as content-free and low efficiency. With the rapid development of the Artificial Intelligence (AI) technology, applications of AI provide significant new methods to the field of teaching analysis. The AI technologies integrated into learning environment promise totally new tools for classroom teaching analysis.

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Specific, new capabilities to computing, including sensing, recognizing patterns, representing knowledge, making and acting on plans, and supporting naturalistic interactions with people (Roschelle et al. 2020) have become potential research methods for analysis on interactions between teacher and students.

Therefore, the aim of the chapter is to analyze effective framework and key technologies to conduct classroom teaching analysis and improvement based on the AI. Two research questions are raised as follows:

1. What could be the effective and comprehensive analysis perspectives for classroom teaching to overcome the shortcoming of common research methods that are often time coding and require activity coding?
2. How to use AI technologies to empower classroom teaching analysis and improvement?

2 Literature Review

2.1 Classroom Teaching Analysis

2.1.1 Time Coding

Since the 1970s, time coding on observing in a live classroom or using video tape recording has been applied in the area of classroom teaching quantitative analysis. Researchers cataloged and counted various kinds of behaviors, interactions, or verbal communications between teachers and students during the whole lesson time every 3 s or 15 s, then calculated the total numbers or frequency of each code to draw a conclusion about the teaching styles or qualities.

For instance, The Flanders Interaction Analysis System (FIAS) and Student-Teacher (S-T) analysis have been applied for verbal and behavior analysis, respectively, since last century. Flanders Interaction Analysis Categories (FIAC) provided a Ten Category System of coding classroom communication. Seven categories for teacher talk, two for pupil talk, and the tenth category for silence or confusion (Flanders 1963). S-T analysis is a quantitative analysis method which simplifies behaviors into two types as teacher behaviors (T) and student behaviors (S) in the lesson time. To improve the efficiency of classroom observation and the accuracy of data, behavioral data is collected every 30 s. Finally, the classroom teaching model was analyzed according to the frequency of behavior conversion and teacher behavior occupancy, which provided a basis for teaching evaluation and theoretical research (Gui et al. 2020).

Although the theory and practice of time-coding classroom interaction segments is a century old, many scholars still use the method for classroom interaction analysis (Amatari 2015), even promoting the original FIAS coding system into the Information Technology-Based Interaction Analysis System (ITIAS) to keep up with the times (Gu and Wang 2004). Some scholars conduct S-T method on videos from several Massive Open Online Courses (MOOC) to detect different teaching styles Sun and Ma (2012).

In general, the time-coding methods shed a light on the quantitative classroom teaching analysis by making behavior or discourse codable and countable. However, time-coding method had to face the inevitable shortcomings like content-free, hard to explain the authentic teaching meaning, and failing to provide valuable feedback for teachers to reflect on and adjust their classroom teaching design and implementation.

2.1.2 Activity Coding

The classroom is a teaching and learning system composed of two dimensions as time and space. The dimension of space could be presented with the activities of teaching and learning. Therefore, some researchers took space into consideration to analyze classroom interactions by applying sampling activities or activity-coding method.

For instance, Rowntree (1990) cataloged learning activities in the classroom into five types: reporting observations or experiences, retelling facts or principles, distinguishing different concepts and principles from examples, enumerating examples, applying new concepts and principles. Mishra and Gaba (2001) suggested analyzing learning activities from two dimensions as questions and reflective actions. Horton (2012) proposed that learning activities should be grouped into absorption activities, doing activities and associative activities. Mu and Zhu (2015) constructed the Teaching Behavior Analysis System with three types of information-based classroom activities including teaching activities, learning activities, and meaningless activities.

Although activity coding had taken content and authentic teaching meaning into consideration which overcame some disadvantages of time coding in some extent, it still failed to answer the problems. Firstly, did all activities deserve to be analyzed if some failed to support the learners' cognitive processes of learning? Secondly, could all kinds of activities possibly be cataloged and analyzed with common agreements on classified rules? If time and activity are not appropriate coding dimensions for classroom analysis, then what should be?

2.1.3 Event Coding

Events of instruction might be the potential answer. Originally proposed by R. Gagné, who is best known for the theories of learning outcomes, learning conditions, and nine events of instruction, the events refer to a series of external stimulus to promote learning in the learner's cognitive processing (Gagné 1970) (Table 1).

Based on the nine events of instruction, scholars and practitioners refined and applied the theories into practice from multiple school levels and subjects like website design (Zhu and Amant 2010), medical teaching (Goode 2018), physics

Table 1 Nine events of instruction (Gagné 1970)

Instructional event	Internal mental process
1. Gaining attention	Stimuli activates receptors
2. Informing learners of the objective	Creates level of expectation for learning
3. Stimulating recall of prior learning	Retrieval and activation of short-term memory
4. Presenting the stimulus	Selective perception of content
5. Providing learning guidance	Semantic encoding for storage long-term memory
6. Eliciting performance	Responds to questions to enhance encoding and verification
7. Providing feedback	Reinforcement and assessment of correct performance
8. Assessing performance	Retrieval and reinforcement of content as final evaluation
9. Enhancing retention and transfer	Retrieval and generalization of learned skill to new situation

teaching in junior high school (Huang 2015), information technology in university (Jing 2012), and graphic design in secondary vocational school (Zhang 2019).

Compared with time and activity-coding methods, event coding provides several advantages for classroom analysis. First, events play a vital role in stimulating learners' cognitive processing. Not all activities could be regarded as events of instructions, but events are all valid activities for learning. Second, the kinds of events are limited in number, with clear rules of classification. Therefore, this study identified event coding as the appropriate dimension for classroom analysis.

2.2 Improvement of Classroom Teaching

2.2.1 Purpose of Teaching Improvement

Classroom improvement is a continuous cycle of constantly discovering and improving problems in real teaching situations. Mehan (1979) proposed a tripartite model of interaction (initiation–response–feedback), which intends to emphasize that feedback is an important tool for promoting classroom interaction and improving classroom teaching through effective feedback. Therefore, the development of teachers and the improvement of teaching quality cannot be separated from teaching improvement.

In early studies, some scholars attempted to improve the classroom quality from different perspectives. For instance, Seldin (2010) used students' feedback to judge teachers' behavior with suggestions as improving the quality of education through group teaching diagnosis. Ellis (1990) analyzed teaching behaviors and evaluated teacher performance through the indicators of recommended teaching behaviors. According to the analysis results, the recommended teaching behaviors include giving students feedback, talking about students' thinking, suggesting extended activities, and calling attention to the competencies of low-status students. Stanulis et al. (2012) considered classroom discussion as a point of improvement and took classroom discussions as a high-leverage practice to effective teaching.

To sum up, the aforementioned researches decomposed the analysis elements of classroom teaching into various dimensions such as teachers and students' behavior, teaching activities, students' feedback, and so on. Although these elements are vital and necessary to the classroom, lack of inclusive and systematic destination made practitioners confused about the analysis results. What is behind the behaviors? What is deep reason for behaviors or discourse analysis? The classroom teaching is a compound structural system. As Bryk et al. (2011) noted that rather than thinking about the proven effectiveness of a tool, routine, or some other instructional resource, improvement research directs efforts toward understanding how such methods can be adaptively integrated with efficacy into varied contexts. Therefore, we need found an inclusive and systematic perspective for classroom analysis and improvement. What it should be? Teaching structure.

No matter what kinds of educational settings like formal or informal, Western or Eastern, old times or nowadays, there are always four important components in a teaching and learning environment as teacher, student, learning contents, and media. The dynamic and systemic relationships among the four components in various teaching and learning contexts are named as teaching structure. Chinese scholar He (2002) defined the teaching structure as clear, stable, and on purpose teaching practice plan which embodied different pedagogies. He summarized out three teaching structures as the teacher-centered, student-centered, and teacher-guided-student-centered structures. According to He (2002), each teaching structure has reasonable application to achieve specific learning goals, but the teacher-guided-and-student-centered structure plays the most important role for students' growth in the classroom or school setting. Therefore, revealing the relationships of the four components and detecting the teaching structure of classroom became the fundamental and inclusive destination for teaching analysis and improvement.

2.2.2 Methods of Teaching Improvement

As the next step of classroom analysis, improving the quality of classroom teaching has been explored continuously in the recent decades. Some of these methods are introduced in this section.

Lesson study is a professional development method that originated from Japan, and centers on the collaborative study of live classroom observation, analysis, and improvement have spread rapidly since 1999 (Lewis et al. 2006). For instance, math teachers from the USA have applied this intervention pattern for carrying out case studies, including four lesson study features (i.e., investigation, planning, research lesson, and reflection) and three pathways through which lesson study improves instruction (i.e., changes in teachers' knowledge and beliefs, professional community, and teaching–learning resources) (Lewis et al. 2009). A framework for conducting lesson study in a teacher development project in Austria established a checklist for research lesson planning to frame teacher and student learning. The framework established the criteria for evaluating teacher behavior and learning and their effects on student learning (Mewald and Mürwald-Scheifinger 2019).

Action research is another research tool for improving classroom teaching. Research indicates that a carefully designed action research project can effectively capture the attention of faculty and administrators and achieve teaching improvement objectives (Cook et al. 2007).

Since the beginning of the twenty-first century, the vigorous development of information technology has brought technological innovation into classroom improvement methods. The time and activity-coding limitations in classroom analysis have been addressed to some extent toward a new level by the integration of cutting-edge technologies. For example, the Classroom Assessment Scoring System observed 180 early childhood classrooms and pointed out problems that should be improved in teaching (Hu et al. 2016a). Digital Interactive Video Exploration and Reflection (Pea and Lindgren 2008) applied the look–notice–comment strategy and a specific software to support the analysis and improvement of teaching after analyzing teaching practice videos (Derry et al. 2010). The Learning Cell platform supports site classroom observation with a mobile application and records before, during, and after class teaching behaviors. After class, teachers in a group engage in a collaborative improvement discussion based on the analysis results (Chen et al. 2018). The Learning Instruction Curriculum and Culture (LICC) model is a classroom observation and evaluation theory framework and uses a series of evaluation tools (Cui 2012). The LICC has 4 dimensions and 68 observation points for classroom teaching. After on-site observation, teachers who use LICC tools record and identify specific problems of the current lesson. Then, the teachers show the analysis results and provide feedback for improvement. Measuring Effective Teaching (MET) was initiated by the Bill and Melinda Gates Foundation (2013) to improve the quality of teaching. MET describes three approaches to measuring different aspects of teaching, namely, student surveys, video recorded classroom observations, and student achievement gains on state tests. The findings suggest that the existing measures of teacher effectiveness provide important and useful information on the causal effects that teachers have on students' outcomes. However, problems in both non-tech- and technology-based improvement methods remain.

First, the evidence of the connection between analysis results and improvement solutions is insufficient. Regardless of the communication after classroom observation (oral or written), most of the feedback about improvement is based on personal teaching experience.

Second, some quantitative research methods focus on a single element, such as behaviors and discourse. However, class is a complex setting containing multimodal data. Evidence from different resources should be considered.

Third, descriptive statistics of the analysis data fail to need effective improvement. In addition to the frequency statistics and percentage calculation of the behaviors or discourse in the classroom, the teaching structure and the specific strategies embody an important educational meaning.

In summary, on the basis of the current research achievements in theory and practice, new methods and technologies should be explored to take classroom teaching analysis and improvement to the next level.

3 Methodology

In this chapter, an AI-supported classroom teaching analysis framework is proposed named as TESTII (Fig. 1). The current TESTII framework is based on the nine major teaching events of Gagné, and the analysis is carried out in the cognitive way of teachers' teaching. TESTII includes the following analysis phases and key techniques.

Step 1: Identifying Teaching Events
As mentioned above, teaching events approach overcomes the time and activity-coding limitations with the advantages of improving the efficiency of classroom teaching analysis and effectively establishing connections between the quantitative structure and the meaning understanding. Therefore, identifying different teaching events is the first step of TESTII analysis.

Teaching events can be extracted and identified from the lesson plan and classroom teaching videos of each teaching case. Lesson plans are mainly composed

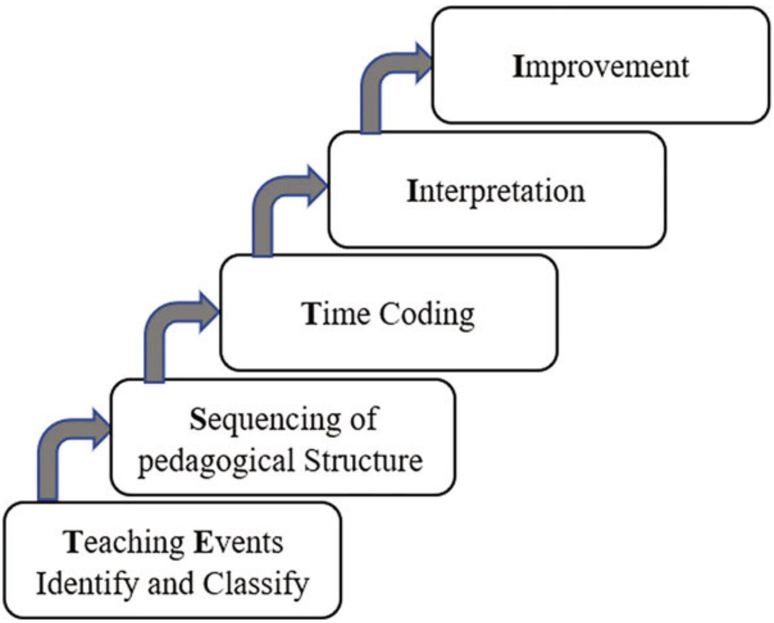

Fig. 1 TESTII framework: AI-supported classroom teaching analysis

of texts. Therefore, the use of natural language processing (NLP) and computer vision (CV) technologies to analyze texts and videos and identify teaching events has become the key approach in this stage. Compared with the common method of relying on manual classroom observation, the use of CV/NLP technology has significant advantages in time and resource savings but fails to recognize the deep meaning of the word, accurately locate the changing expressions of the same type of activities or events, and find the meaningful sequence in the teaching structure. Therefore, the human–machine cooperation mode is adopted for the recognition of teaching events, and the specific analysis steps are as follows.

The first stage involves the collection of videos of each lesson and the random selection of static images. The researchers classify part of the scene data, and these labelled data are used as the training set to train the neural network model of scene classification. Then, computer vision technology is applied to detect the key scenes and cut the video into pieces for possible teaching events recognition (Fig. 2).

Fig. 2 Detecting the key scenes of classroom teaching by computer vision

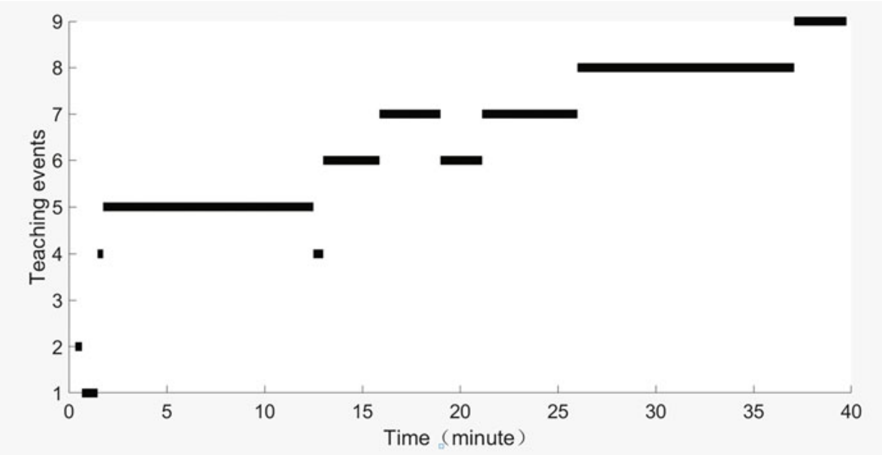

Fig. 3 Sample diagram of time distribution of teaching events

Second, NLP technology is applied to select teaching events using key words of every event. The researchers divide the teaching events into labels and mark texts to form corresponding judgment rules. Then, deep learning model Word2vec is used to generate an event classifier on the basis of the gate recurrent unit (GRU) to judge the accuracy of the model. Furthermore, the specific teaching event was recognized through NLP technology, and the time distribution map of teaching events for a lesson could be generated visually as shown in Fig. 3.

After using the aforementioned method to identify the teaching events, the study found that some classrooms did not have all the nine teaching events. For example, several teachers did not stimulate the recall of the previous learning but directly informed the learners of the objectives. The phenomenon results in some teaching events being left blank in the statistics. Therefore, the TESTII framework groups the nine teaching events into teaching phases.

Actually, grouping teaching events into phases is not a new idea. Gagné classified the nine teaching events into three teaching phases, namely, preparation, instruction, and practice, and assessment and transfer (Gagné 1970). On this basis, Indian scholars Mishra and Gaba (2001) divided 15 teaching events into four teaching phases including introduction, new knowledge teaching, conclusion, and evaluation. In combination with the existing research results and our classroom observation, this study grouped nine teaching events into four teaching phases as introduction, new knowledge teaching, conclusion, and migration, as shown in Table 2.

Step 2: Sequencing Pedagogical Structure

The significant value of classroom teaching analysis is to identify high-quality teaching. Chinese scholar He (2002) proposed that the teacher-guided and student-centered teaching structure is the foundation of high-quality teaching and learning in the classroom. In He's opinion, the teaching structure refers to the stable structural

Table 2 Nine teaching activities and teaching phases

Instructional event	Teaching phases
1. Gain attention	1. Introduction
2. Inform learners of objectives	
3. Stimulate recall of prior learning	
4. Present the content	2. New knowledge teaching
5. Provide 'learning guidance'	
6. Elicit performance (practice)	
7. Provide feedback	
8. Assess performance	3. Conclusion
9. Enhance retention and transfer to the job	4. Migration

Table 3 Teacher and student roles in the SPS

Role type	SPS	Code	Description
Teacher roles	H	T1 Lecturer	Oral explanation and explanation by the teacher
		T2 Questioner	Teachers directly ask questions and students answer directly
	h	T3 Instructor	Teachers provide models and guidance for everyone to learn, which can be words, actions, and process guidance
		T4 Facilitator	The teacher's response and handling of students' responses and behaviors
		T5 Collaborator	Teachers organize and guide students to discuss
Student roles	L	S1 Active learner	The students manage learning opportunities
	l	S2 Passive learner	The students may have some passive responses

form of the teaching process under the guidance of certain educational ideas and teaching and learning theories. This structure is the concrete embodiment of the interaction between the four components of the teaching system, namely, teachers, students, content, and media. However, the teaching structure is a macrolevel theory, and specific and relatively microlevel theories should be applied to directly identify the structure.

Sequencing of Pedagogical Structure (SPS), proposed by Jacobson et al. (2013), regards the teacher-centered direct instruction and student-centered learning as two poles. According to the proportion of teacher guidance or student discovery learning in different teaching phases, the SPS marked the phase with H or h means large or small proportion of the direct instruction of the specific stage, same for L and l about the discovery learning.

The SPS theory showed advantage in analyzing the teaching structure to some extent, but it failed to address the roles of teachers and students in the different phases. Therefore, this study introduced Schulman's classification of teacher roles (Scheurman 1998) to facilitate coding for SPS as seen in Table 3.

Combining the theories of SPS and teacher roles, this study analyzed four lessons as example A, B, C, and D. Results are shown in Table 4. Time sequence is presented

Table 4 Example of four lessons with SPS coding

Lesson	Phase 1	Phase 2	Phase 3	Phase 4	SPS coding results
A	Teacher plays the video	Student cooperation	Students do exercises; Teacher analysis and statistics	Teacher leads students to summarize the methods of observing objects.	H→(L+h)→(L+h)→(h+L)
B	Teacher shows voting box	Student cooperation	Students build models; Teacher evaluates models	Review and summarize new knowledge together.	H→(L+h)→(L+h)→(H+l)
C	Teacher shows picture	Student cooperation	Teacher assigns exercises	Review and summarize new knowledge together.	H→(L+h)→H→(H+l)
D	Teacher shows the cube	Teacher asks questions	—	—	H→H

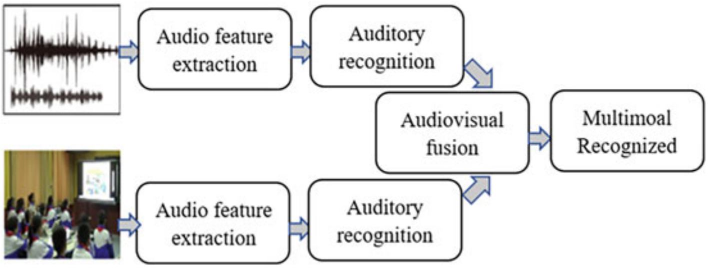

Fig. 4 Multimodal recognized analysis for interaction

as well. The plus sign (+) indicates simultaneous pedagogies, while the arrow (→) indicates the sequence. The most common sequence in teaching is the high-to-low (H→L) sequence, such as a lecture followed by unsupervised homework, while the low teaching structure sequence (L→H) is probably the least common (Hu et al. 2016b).

To apply NLP technology, a teaching method structure sequence classifier should be established first. The input of the classifier is textual data, which contains contextual information. For a better understanding of the meaning of a sentence or word in the input data, the attention mechanism is introduced, which has the advantage of being able to intuitively explain the text content and show the importance of different sentences and words to the classification category. Sentence core words and event core sentences can be determined by the attention mechanism. The sequence of the teaching method structure is given by modeling sentences and chapters in text data.

Step 3: Time Coding for Interaction

Interactions between the teacher and the students in the classroom are important indicators of high-quality classroom teaching. Compared with the traditional single resource analysis methods, such as FIAS or S-T behaviors, TESTII conducts multimodal recognition via visual and auditory fusion on behaviors and discourse (Fig. 4). Instead of sampling the entire lesson through the time process, time coding is adopted within the teaching phases composed of teaching events. Then, the teacher-student interaction is analyzed in this stage, providing evidence for interpreting the teaching method structure sequence in the lesson examples.

To analyze the teacher-student dialogical interaction in different teaching phases, this study divided the teaching events into labels firstly and marked texts to form specific judgment rules. Subsequently, Word2vec, a deep learning model of natural language understanding, is used to train and verify the data. Then complete the automatic classification, analysis, and statistics of dialogical interaction in the current teaching phases.

As for the analysis dimension about behavioral interaction, the teaching scene is preliminarily classified according to the static frames. Then, the key interactive devices in the video are detected through the target detection method. Finally, the actions of teachers and students are identified based on the deep convolutional neural network method. For instance, computer vision technology can judge the behaviors in the video like raising hand, walking, standing, writing on the blackboard, operating the tablet, and so on through matrix identification. Based on the analysis results, the features of teaching and learning behaviors could be figured out automatically.

Step 4: Interpreting the Result of Analysis

The explainability of the decision made and the actions taken is the core appeal of the future development of artificial intelligence and the premise of man–machine mutual trust. Teachers are not professional data analysts and thus require explanations that are easy to understand and conform to the rules of education and teaching to help them understand the analysis results of the machine, such as data content analysis, analysis of logic, analysis results, and problems identified.

On the basis of the aforementioned three steps, an interpretable, evidence-based visual analysis report is presented in Step 4. The report includes the number and time distribution diagram of teaching events in a lesson, the sequencing of the pedagogical structures of the classroom teaching, and the interaction of behaviors and discourse within each teaching event. A readable, effective, and persuasive data analysis report will help teachers implement specific teaching improvements while improving the credibility of teaching improvement plans, facilitating the transformation of data-driven teaching analysis to knowledge-driven teaching decisions.

Step 5: Improving Strategies Recommended

Providing effective improvement strategies for teachers on the basis of the analysis results of classroom teaching is the last and the most valuable step. According to the analysis results, the features of classroom teaching are identified. Then, the features are classified into kinds of teaching problems, such as teacher-centered structure and passive learning. Subsequently, the problems are matched with the database of effective teaching strategies and cases, which are recommended. Following the instruction and recommendation, which are collaboratively developed by the human–AI system, the teachers improve the teaching structure. The proposed AI-based analysis method takes the classroom as the main analysis object and it provides opportunities to build a flowchart model of classroom teaching analysis and improvements using Analysis–Problems–Strategies–Practice (APSP) method (Fig. 5).

The APSP model draws lessons from the core idea of “problem-solving and continuous inquiry learning” in the improvement science to identify shortcomings in teaching and improve teaching quality effectively.

The APSP cycle aims to answer four questions about the teaching improvement. (1) Analysis: What are the characteristics of the class? (2) Problems: What specifically are we trying to accomplish? (3) Strategies: What change(s) might we introduce and why? (4) Practice: How will we know that a change is actually an improvement?

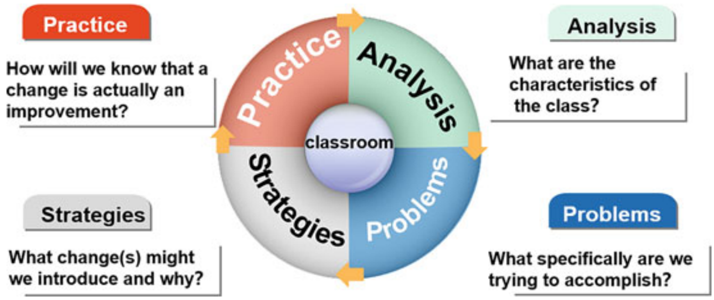

Fig. 5 APSP cycle

To answer the four questions, the current chapter conducted four steps. Firstly, detecting the features or characteristics of the classroom teaching for further analysis; secondly, the features are categorized in different teaching structure types to address the problems; then, recommended teaching strategies for improvement matched to problems; finally, the strategies are applied to the teaching practice to improve the teaching quality.

Meanwhile, the APSP model integrated AI and human–AI technologies for recommended improvement strategies. In the beginning of our research process, experienced K12 teachers are invited as human experts to analyze many lessons and propose improvement strategies according to various problems. The experts' opinions and wisdom are classified into "question–strategy" pairs and stored in the database for machine learning. Then the experts are invited again to ensure or revise the "question–strategy" pairs created by machine learning which construct the human–AI collaboration improvement mechanism in the APSP model.

4 Conclusion

The chapter summarizes the development of classroom teaching analysis and improvement. Aiming at the problems encountered in the current stage, the TESTII framework of artificial intelligence is proposed to support classroom teaching analysis, taking teaching events as the basic analysis dimension, and forming five steps for teaching improvement.

Future teaching analysis would benefit from the integration with AI technologies. AI has the potential to make powerful impacts on the future of teaching and learning, which are reflected in the learning scene and the teaching process. AI for learning provides many applications and multimodal channels for supporting people in cognitive and noncognitive task domains (Niemi 2021).

TESTII framework has some limitations. The analysis of classroom teaching is based on event coding followed the Gagné's nine teaching events theory which is teacher-centered perspectives. Therefore, the student-centered classroom such as inquiry-based learning, discovery learning should be considered in the future. The other shortcoming is that the major lessons are from elementary Math classroom. We would expand the research lesson database in the future.

In summary, the TESTII would keep on building multimodal analysis and human-AI integrated improvement mechanisms to optimize the quality of classroom teaching and learning. In follow-up research, artificial intelligence technology is expected to be applied to teaching practice and integrated into the main process of education, so as to form a deep integration of artificial intelligence and normal classroom teaching and make a high impact on the quality of teaching and learning in classrooms.

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