Course Design for Tunnel Engineering with Complexity under Consideration

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Abstract
In the recent years, Chinese infrastructure and civil buildings are of increasing features in type, quantity and dimension. The high education of Civil Engineering and related subjects has been prosperous for more than two decades in China. However, similar challenging situation, with which the education of Civil Engineering in industrialized countries was faced at the beginning of this century, appears in China nowadays. To adapt to the changing and challenging situation, such as with course time decreased, content and requirement increased, the teachers of professional courses in the field of Civil Engineering have to redesign course plan. This contribution presents the course design for Tunnel Engineering with complexity under consideration at Chang'an University in China. The complex features of the course Tunnel Engineering are first analyzed, with special reference to the course content and main principles related to the major teaching points. The complex features of the course mean the requirement of systems thinking in course learning and teaching process, which should be based on an effective course design. The application of systems thinking rules and complex adaptive systems principles in the course design is presented, with three-step systems mapping method as example, including (1) mapping the course content, (2) activating the learning content, and (3) checking (assessing) both the content and the underlying thinking skills articulated in the lesson frame. The practice and results of the course design for Tunnel Engineering indicate an active effect to foster student optimal learning and to promote student metacognition developing.

Keywords: Complexity, Systems Thinking, Mapping Method, Course Design, Tunnel Engineering

Introduction

Teaching at college is not only to present information to students involved, but to transfer specified information into student's knowledge. We are in an age of information and innovation knowledge driven society, which is with features of changing and challenging. The ability to cope with this situation requires developing the skill of learning how to learn (Watson, 2019).Thanks to the digitalization and internet technology, the acquisition of information is generally not difficult in learning and teaching process at a university and how to use information available reasonably and efficiently is the crux of the process. An arbitrary accumulation of information will not automatically become knowledge, which is structured information with systems thinking (Cabrera & Cabrera, 2015). Students need develop not only cognition but also metacognition in a systematic thinking way (Gell-Mann, 1995; Fleming, 2014). Therefore, a student learning-centered course design and its execution plan should be beneficial to the development of student's self-consciousness in the learning and teaching procedure.

In the recent years, infrastructure and civil buildings are of increasing features in type, quantity and dimension, such as the tunnel and underground structures in China. The information related to a subject or specialty is increasingly cumulating with time. This situation is challengeable to the teaching of a professional course at a university, as the teaching time for a tradition professional course is limited or even decreasing (Ma, 2021). To adapt to the situation, the efficiency of a course teaching and learning process should be increasingly improved to meet the requirement of a changing situation.

In modern education, complexity is considered a central theoretical concept and the application of complexity is relevant in education (Mason, 2008a, b; Cabrera & Cabrera, 2019). Considering a student's learning is a performance in a complex organizational processes, we educators need systems thinking models rooted in complexity theory (Kuhn, 2008), and as suggested by Cabrera & Cabrera (2019) that "those of us involved in education must understand complexity and in particular complex adaptive systems", to help students to develop adapting ability.

Following the three-step teaching method that involves framing, activating, and checking the knowledge a teacher wishes to impart to students (Cabrera & Cabrera, 2019), the course design for Tunnel Engineering at Chang'an University is presented, with complexity under consideration, to reinforce applying systems thinking in course practice.

Features of the course Tunnel Engineering

Tunnel Engineering is relatively new in comparison to the other subjects, such as industrial and civil architecture, geotechnical engineering, in the field of civil engineering. However, Tunnel Engineering is increasingly assigned as an independent course at a university since 1970s, from which tunnel and underground structure are increasingly built for various usages. In the Tunnel Engineering course design, the following complex features are considered.

1. Complex features of the subject content

As a course, the information related to the following features of tunnel or underground structures should be presented in a proper way: (1) underground structures with various types and functions; (2) structures in various building conditions and environments; (3) structures with limited and specified operational environments. In a tunnel project, these features are considered, such as in terms of requirement, building and operational conditions, cost and time schedule, and the risks related to the project. All of these parameters are presented in the content of planning, design, construction, operation and management stages, which are also corresponding to the execution stages of a new project (Ma, 2020). In practice, the upgrade and rehabilitation of an existing tunnel are always necessary with operational time increasing and the technical standards for tunnel operational environments are developing with time. The related information, theory, principles and engineering skills are learning and teaching content, such as in terms, definitions, concepts, analysis, calculation, and case histories so on.

The above-mentioned course content is not only rich in formation and meanings, but also complex. For example, in a general view, a tunnel project is executed in stages, which conditionally and non-linearly influence or relate to each other, in terms of project considerations, such as usages, building and operational conditions, cost and time schedule, and related risks. The project influence factors, such as related to the above-mentioned features, will interact in a dynamic mode in the project stages. In a specific view, a term is usually presented in much simple and limited way, such as in definition, while systemic and complex features is under consideration when it is used in the main parts the course. For example, the ground in a tunnel definition is considered building environment. The surrounding rocks which is the ground parts that have direct influence on the behavior (e.g., stability) of a mined tunnel, are the structure components of the tunnel in a general sense. The behavior of the surrounding rocks of a tunnel could be a complex system and should be presented with the interaction between the tunnel supporting system (i.e., structure in a narrow sense) and the surrounding rocks under consideration.

As the course time is limited, we could only present some the information related to the course subject. Considering the complex features of the subject contents, the course information sampling and teaching plan design need the help of systems thinking, with complexity under consideration.

2. Complex features of the subject major principles

As the above-mentioned, the functions and types of tunnel and underground structures are increasingly diverse and meaningful. So are the major tunneling principles in terms of tunnel planning, design, construction, and operation and management. To present a tunneling principle, there need enough space for its complex features. For example, a mined tunnel is built in ground and the features of the tunnel are strongly related to the ground conditions. The following principles often come into play in project different stages, respectively.

(1) *Planning stage*: Ground conditions have strong influence on the project feasibility and risk level, tunnel type and construction proposals, and their corresponding cost and time schedule plan.

(2) *Design stage*: The grounds around a tunnel, i.e., surrounding rocks, are considered parts of the planned tunnel structures. The assessment of the properties of the surrounding rocks, such as stability or self-supporting capacity, is the foundation for the structure (or supporting system) design, construction plan proposing, risk evaluating and controlling planning, the evaluation of cost and time schedule.

(3) *Construction stage*: The ground conditions ahead of excavating face need identification in an advanced way, and the predicted behaviors of the surrounding rocks in design, especially for these with poor self-supporting capacity, need in time checking according to the specified tunneling procedure, such as with the help of instrumentation and monitoring.

It is noted that the behavior of the surrounding rocks is of dynamic features, which are related to various factors, including the geometrical features of the tunnel, ground conditions without and due to tunneling disturbance, control and protection measures (e.g., supporting system) to the disturbance and their applying time. For the tunnels, which are built in grounds being sensitive to tunneling disturbance and the applying effects of the supporting system, the behaviors of both the surrounding rocks and the supporting system are strongly related to their interactions, which are of non-linear and time-effect features. It is clear that the above-mentioned principles work in a complex system way. This is also the reason that a tunnel project is often of unique features.

Considering the above systemic and complex features of the Tunnel Engineering as a subject, we design the course learning and teaching with complexity under consideration. For example, the system relationships of the above-discussed course content and related major principles are presented in Figure 1.

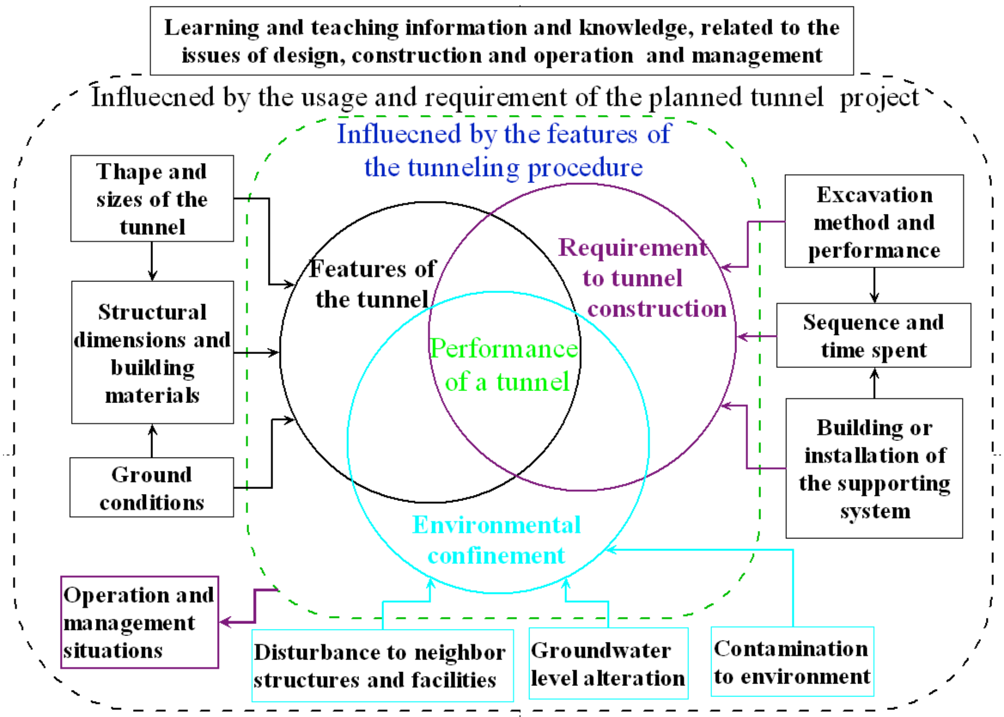

Figure 1: System relationships of Tunnel Engineering content and related major principles.

Design for the course Tunnel Engineering

As Murray Gell-Mann (1995) stated that complexity "illuminates the chain of connections between the simple underlying laws that govern the behavior of … the complex fabric that we see around us, exhibiting diversity, individuality and evolution", and complex things are considered the product of simple rules (Cabrera & Cabrera, 2019) or complexity depends on simplicity (Gell-Mann, 1995). On the other hand, a learning and teaching at a university involves human systems and is of complex, nonlinear, multidimensional and interconnected features (Kuhn, 2008). And therefore, we should seek for complexity theory to provide us insight into the nature of human collective behavior (Cabrera & Cabrera, 2019) in learning and teaching plan design and implementation, in favor to metacognition development.

1. Complex systems thinking and metacognition development

Education is a complex system process and requires applying complexity system thinking to meet the challenges in learning and teaching activities (Cabrera & Cabrera, 2019). It is beneficial being conscious of the interrelation of all aspects of the educational system to improve learning and teaching results. In the following, we explore how systems thinking can be used to help students and teachers build metacognitive learning strategies.

It is beneficial applying Complex Adaptive Systems (CAS) in education to develop student abstract thinking and to make the teaching easier and clearer (Cabrera & Cabrera, 2019). Good course design and implementation plan help students develop metacognition, which is considered one of the twenty-first century learning skills, such as creativity, emotional intelligence and critical thinking (NRC, 2012). It is on a right track to develop metacognition (Cabrera & Cabrera, 2019) with the application of CAS, following the four cognitive skills or rules (DSRP): (1) making distinctions, (2) recognizing systems, (3) relationships, and (4) perspectives (Cabrera & Cabrera, 2015).

(1) *Distinctions*: Determination of learning and teaching content and a way of active study. Individuals make distinctions when they identify any thing or idea (Cabrera & Cabrera, 2019). In a course design, teachers first determine learning and teaching content through the creation of a boundary that identifies specified content from what it is not. Be sure that a course plan proposer is in awareness of the perspectives implicit in boundary-making or content choosing. What should be underlined is how to guide student to make distinctions consciously in a well-designed learning and teaching procedure. As one's cognition is improved through objective content identification and the awareness of the perspectives implicit in boundary-making (Cabrera & Cabrera, 2019), it is important to make clear the specified perspectives for each point of the learning and teaching content as early as possible. Therefore, students would have a chance to actively and effectively make distinctions in their learning activities.

(2) *Systems*: How to present the planned content in terms of the relationship of details (parts) and whole content. An idea or learning point can be considered as parts of a whole in terms of the concept of reductionism and holism simultaneously, as systems is made up of the co-implying elements part and whole (Cabrera & Cabrera, 2019). This means we can present a specified content in details while considering the related parts in a whole, which is made up of even smaller parts, such as in forms of the concepts of a subject, the types and elements of structures. How to present the planned content is also perspective-oriented, since one's perspectives affects not only her (his) understanding of the system, but also how to demarcate a specified learning or teaching point in terms of systems.

(3) *Relationships*: Developing systems thinking and problem-solving skills through making relationships and connections between and among all information. Knowledge is structured information. Our minds need constantly making relationships and connections between and among all information we encounter and process (Cabrera & Cabrera, 2019), although the process could be performed subconsciously. For example, determining causality is well-used in problem-solving and unconsciously creating relationships usually in an oversimplified way. In a learning or problem-solving process, we need making relationships yet somewhat

obscured within a system. The guideline based on the above-mentioned learning content presentation design is helpful in making the relationships, in terms of systems thinking and problem-solving skills development. A good practice is that students are aware of the learning information relationships they develop, such as through underlining the causality, which reflects the complexity of a practical problem or knowledge point, in an active learning process.

(4) *Perspectives*: Skills of identifying perspectives and considering alternatives in understanding information and solving complex problems. Perspectives consists of two elements: point and view (Cabrera & Cabrera, 2015), i.e., "A point is the idea/thing that is looking or focusing, while a view is the idea/thing that is being looked at or focused upon". As we perceive a point or view of the reality in systems thinking, we frame the related information. In other words, the issues we look at change as we change the way we look at the issues (Cabrera & Cabrera, 2019). So, students should be encouraged to see another way to do/read/interpret what the others have presented in learning and teaching procedure. The skills of being able to identify perspectives and then consider alternative ones are a great advantage for understanding and solving complex problems. Therefore, seeing from multiple perspectives is one of the practical ways of applying the perspective rule. When we identify distinction, system and relationship in systems thinking, the related perspectives are embedded in the identifying process (Cabrera & Cabrera, 2019).

In practice, the four simple cognitive rules of systems thinking (DSRP) are considered as the foundational cognition building blocks, which could come to play simultaneously or in varying order (Cabrera & Cabrera, 2019), as shown in Figure 2. For example, students can apply the rules to build knowledge by structuring the related information to explore new channels of thought not yet presented in course information. This is of great benefit for structuring information, problem-solving skill development and innovation (Cabrera & Cabrera, 2019).

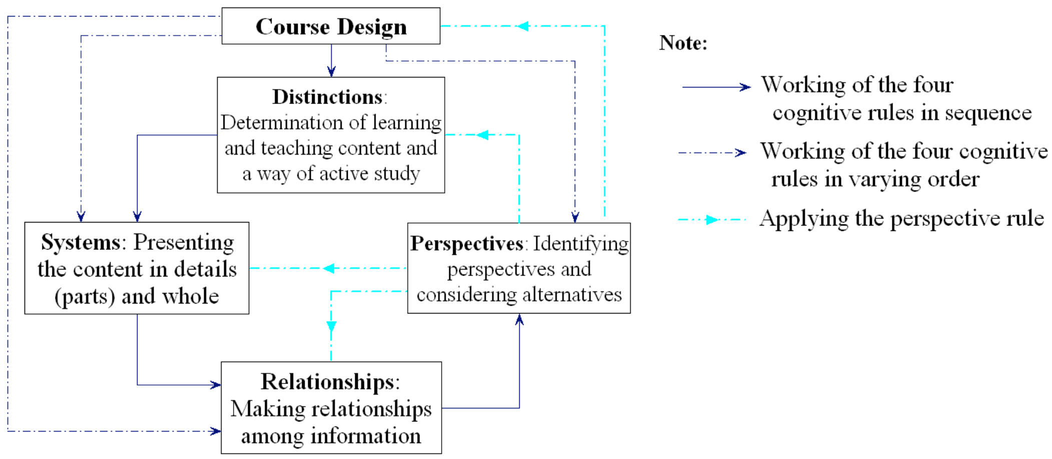

Figure 2: Application of the four cognitive rules in varying order in a course programme.

2. Application in Course Design

As information is available, it is critical to build meaning or develop thinking from the information. In other words, educators are not only teaching ideas (information), but also thinking skills to help learners to build knowledge through exploring deep meaning from that information. Course design and plan implementation should be learner-centered, such as to improve student learning outcomes. The tools and resources we integrate into educational settings are to help student learning and structuring information or knowledge building. The DSRP cognitive architecture can enhance students' awareness of their metacognition, intelligence and effectiveness (Cabrera & Cabrera, 2019). As individuals are made aware of the way they think, they improve learning achievements (Fleming, 2014). To make learning and teaching effective, we follow the three-step systems mapping technique (Cabrera & Cabrera, 2019): (1) mapping knowledge (the content), (2) activating the knowledge (learning content), and (3) checking (assessing) both the content and the underlying thinking skills articulated in the lesson frame by learners, in the course Tunnel Engineering practice, such as to present idea, topic, principles and case histories, as shown in Figure 3.

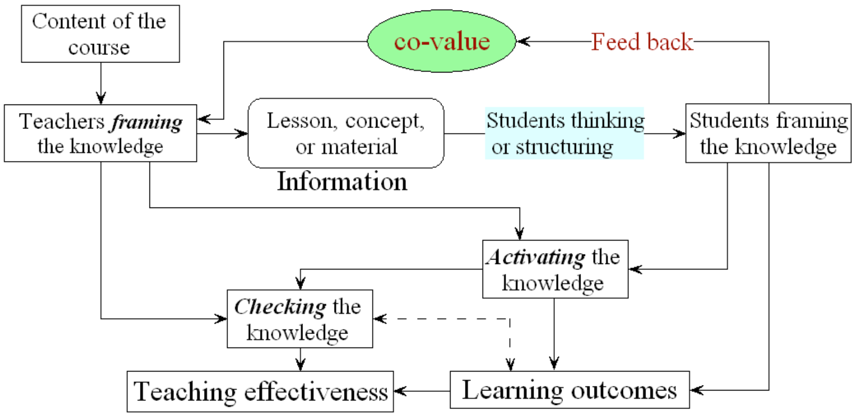

Figure 3: Application of the three-step mapping technique in the course programme

2.1 Mapping the course content

As teaching activity is student-centered, mapping knowledge means presenting the content to be learned and taught, in a transparent manner, such as in verbal, visual, physical, form, etc. Since knowledge is structured information, such as following cognitive rules, we consider that a learning and teaching procedure starts from knowledge framing to plan the course. The knowledge mapping should be functional to help a teacher and learner in organizing information according to cognitive rules, e.g., the DSRP rules. In other words, well-framed course design and implementation plan present related information, execution procedure and learning task with good objective clarity, to encourage students to actively learn through thinking rather than just memorizing information. An ideal way is to frame the related knowledge by a teacher and student co-creating mode (Ma, 2021).

In brief, the criteria for a good or effective knowledge mapping include: (a) making clear the course learning contents and objectives or rubrics; (b) presenting the execution procedure of the course activities, with specified key points for each of the phases or steps and the explicit clue of learning skills; (c) the content presentation of contemporary, concise, attractive, easily understanding features for each learning and teaching point, but of system features in a whole. For example, the course content related to the features of tunnel structures should be presented in terms of planning, design, construction, and operation and management, which will focus specified points a stage, respectively, but with the requirements from the others under consideration as a whole project.

2.2 Activating the knowledge

To increase student engagement and deepen understanding, the purpose of this step is to activate the content and thinking skills the teacher has framed, such as through a reflection on the student learning experience. The planned activities, such as a scenario of problem-solving, storytelling, case history analyzing, or experiential activities, could connect the lesson content and the systems thinking skills as emphasized in the content mapping.

The effective activating knowledge is ground on students' prior information and experience (Ferlazzo, 2015). Therefore, the first step is to know the previous knowledge of the related subject, such as through a quiz or content-specified problem-solving activity at beginning. The learning and teaching plan is tuned according to the activity results. This means a well-designed course syllabus and its implementation plan should be a modest rigidity with a structured flexibility, which improve and perfect itself via interactions within the learning and teaching system (Doll, 2008). The activating knowledge is an effective way to articulate connection and concretization of subject abstract concepts and to enable students to understand related learning content in systems thinking or build knowledge.

A well-designed activating is also a process of increasing student engagement and systems thinking application. For example, of the features of tunnel structures, activating points for the multi-stages learning and teaching content vary, but focus on the above-mentioned features of tunnel engineering, as shown in Figure 4.

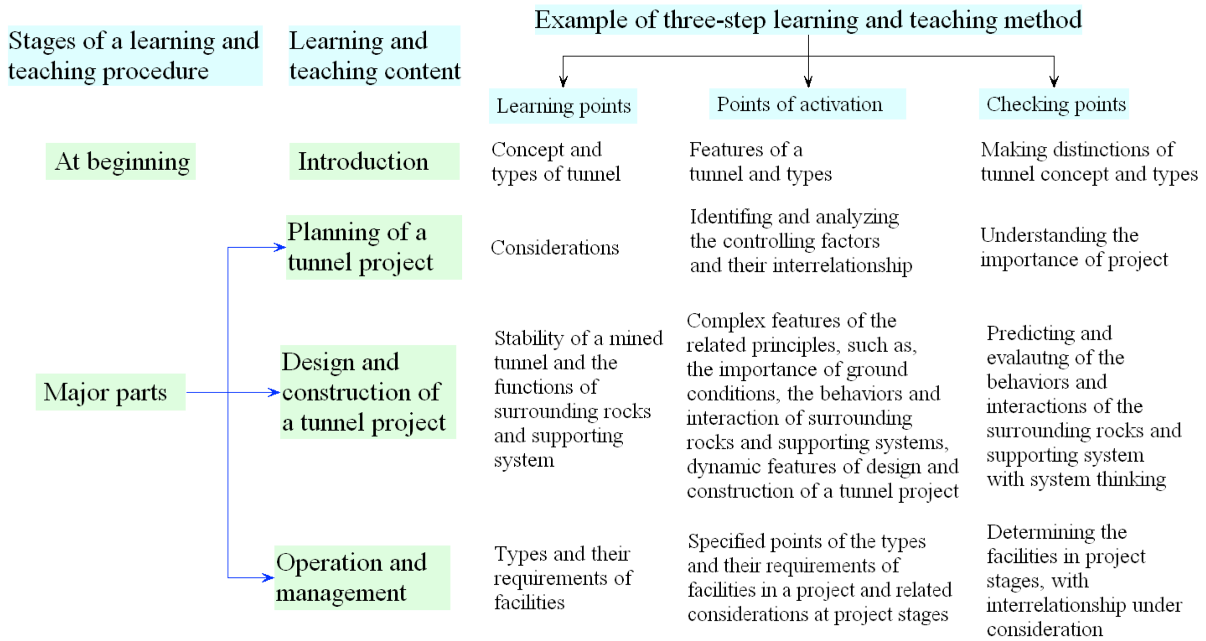

Figure 4: Example of the three-step systems mapping technique application.

For example, starting from a course introduction, the concept and types of tunnel are presented, with the question: what are the general features of a tunnel in the field of transportation? The response could be underground structure, engineering production, function (building purpose) and structure features (shape, size, ratio between length and span). At the end of this activation, students should be able to distinguish a tunnel in the field of transportation by identifying its three features from a tunnel in common sense, with explicit boundary distinctions from the concepts of ground structures, natural tunnels, and tunnel and underground structures with other usages, which are also corresponding to the types. Ultimately, students would also gain a clear understanding of both the distinguishing tunnel and ground structure, and the value of making clear distinctions in other course concepts.

Of the knowledge of tunnel planning, almost all of the related influence factors in Tunnel Engineering are under consideration, such as the requirements of a tunnel, features of the planned tunnel (e.g., type, geometry) building conditions (e.g., geotechnical, constructability, techniques availability, environment and neighbor structure sensitivity), social factors (e.g., cost affordability and time schedule acceptability, social and political influence), and related risks. The related activation focuses on the considerations in a system way, how to identify and analysis the controlling factors in a practical project, and the general features of the planned tunnel. The related learning point activation helps student to understand the importance of a good project planning and to develop skills of analyzing information available with the application of systems thinking.

The contents presenting the knowledge of tunnel design and construction are major parts of the course. Of the related knowledge, there are various points deserve activating. For example, the related activating knowledge practice will enable students to understand the importance of ground conditions to the stability of a tunnel, such as in terms of approximating the features of the tunnel surrounding rocks, the behaviors of the surrounding rocks and supporting system, as well as the interaction between the ground and supports. In this process, we underline the complex features of the related principles, including the structural functions of the surrounding rocks, how to protect or to mobilize the self-supporting capacity of the surrounding rocks with the features of stand-up time short or relatively long, respectively. The relationship between the design and construction are activated under a system consideration, such as in terms of dynamic design or "design as you go" during the construction of a complex tunnel project.

The knowledge activation of the operation and management content stresses both in the specified points of the types and their requirements of facilities, such as ventilation and lighting, and in the interrelationship of the planning, design, construction and operation issues in systems thinking. For example, the types and their requirements of operational and management facilities of a tunnel are mainly related to the features of the tunnel, such as type and function, geometry (e.g., length and span, shape and area of cross section), traffic volume and its composition. The requirements of the facilities should be increasingly considered from planning to design stages. The required facilities come into practice through construction, whose method optimization is often confined by the installation space features. The running of the operational and management facilities is issue related to project cost, serving and risk levels, and environment effect. All of these results could trace back to the project planning and design.

2.3 Checking the knowledge

As the teaching is learning-centred, the learning outcomes need evaluating to ensure the desired course objective. The checking is to assess student understanding of information and thinking, with specified checking points (Fig. 4). The typical measure should have the parameters of determining whether learners are building the knowledge the teacher initially framed and then activated (Cabrera & Cabrera, 2019). The checking measures should match with the student experience, such as in terms of pre-lesson, within classroom activity and post-lesson. Therefore, it is important that students performing self-assessment and reflection to check their own understanding out of classroom and to increase their metacognitive awareness (Cabrera & Cabrera, 2019).

In a student-centred process, the evaluation of student learning outcomes is performed with the designed points and related rubrics (Fig. 4), which are of pre-lesson explicit form to the students. The evaluation practice shows that incentive is better than punishment (Ma, 2021), such as for the achievements of quiz, assignment, presentation and test both in classroom and after class. The checking results of the learning outcomes is active. This implies that the application of complex systems thinking in the course design, together with the three-step mapping method in learning and teaching process, is beneficial to foster student optimal learning and to promote metacognition, implying an improved learning outcomes.

On the other hand, the checking activity in time is also an effective approach to apply co-value method in course plan implementation (Ma, 2021) and to timely response to the appropriateness of teacher course framing (Fig. 3).

Conclusion

With the application of Complex Adaptive Systems (CAS) and three-step mapping method (Cabrera & Cabrera 2019) in the course design for Tunnel Engineering, with complexity under consideration, the following conclusions can be drawn.

(1) Considering the complex features of both student knowledge building and the course Tunnel Engineering, the application of the three-step systems thinking mapping method is necessary and beneficial for the course design and plan implementation in favor to students' knowledge building.

(2) The practice and the results of the application of CAS and three-step mapping method indicate a positive effect to foster student optimal learning and to promote student metacognition developing.

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