

Modeling STEM Learning Design Competence Through Discourse Analysis

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Abstract—Modeling STEM learning design competence is critical in support of STEM teacher professional development. This study collected 9686 utterances of 33 pre-service STEM teachers from an online STEM learning design environment and modeled STEM learning design competence using epistemic network analysis (ENA) approach. Moreover, this study investigated the relations between collaborative design process and design outcome. We categorized high and low-performing groups based on their STEM lesson plans and then compared their STEM learning competence networks drawn from conversation. The findings revealed that there are significant differences in the networks between high and low-performing groups, which may contribute to the quality of their lesson plans. To further explore the developmental trajectory of STEM learning design competence, we modeled the competence networks of the two groups at different design stages. The findings show that these two groups represent two learning design patterns, similar to traditional learning design and backward learning design.

Keywords—STEM; learning design competence; epistemic network analysis; discourse analysis

I. INTRODUCTION

As the recent demand for innovative and interdisciplinary talents in science, technology, engineering, and mathematics (STEM), it is becoming a critical need in teacher education to cultivate high quality STEM teachers [1-2]. Despite opportunities for teachers to participate in STEM related professional development have increased [3], it remains unclear regarding how we can cultivate and evaluate STEM teacher effectively, especially STEM learning design competence [4-5]. To address these issues, this study adopted a novel approach to quantify the development of pre-service STEM teachers' learning design competence through discourse analysis, and connected the design process with the design outcome. In the present study, the pre-service STEM teacher training program was developed based on the notion of "virtual internship" [6], in which pre-service teachers involved in collaborative STEM curriculum design through active interaction with both tutor and peers in virtual internship context.

Studies have shown that there are differences in design thinking between learning designers at different levels, such as novice and expert [7]. The goal of this study was to model STEM learning design competence, and to identify differences of learning design competence development in

the context of collaborative STEM curriculum design. The findings will provide evidence for improving STEM teacher training programs and designing effective instructional scaffolds. Accordingly, this study seeks to answer the following research questions:

- 1) How do high and low-performing pre-service teachers develop learning design competence during STEM learning design meetings?
- 2) What relationship, if any, exists between pre-service teachers' STEM learning design competence and their lesson plans?

II. THEORETICAL FRAMEWORK

A. Teaching STEM Learning Design

Learning design is a complex, ill-structured, problem-solving activity that involves decision-making procedures [8]. Pre-service teachers should not only learn theory, but also bridge theory and practice through real-world experiential learning [9]. One way to provide novice learning designers authentic professional practice opportunities is to participate in school internship program. Advances in technology have facilitated online learning, and made the virtual internship a reality. For another, studies have shown that involvement in collaborative curriculum design contributes to teachers professional growth [10]. Professional development experiences that allow inter-disciplinary teams of teachers to engage in learning design activities can help promote connections within and across STEM domains [11]. To facilitate these connections, we developed a virtual internship environment for pre-service teacher training (Figure 1), which moves from traditional face-to-face learning to online environments, and brings together pre-service teachers to engage in collaborative STEM learning design activities. Virtual internship allows trainee teachers to apply their content knowledge and learning theories to the learning design practice. This approach can not only enable pre-service teacher to design lessons in an authentic, guided, collaborative online environment, but also allow teacher educators to evaluate STEM learning design competence of pre-service teachers through analyzing their learning data automatically recorded by the system.

B. STEM Learning Design Competence

The American Society for Training & Development (ASTD) defines competencies as clusters of skills, knowledge, abilities, and behaviors required for job success.

To facilitate student learning, learning designers must understand and be able to apply theories and design principles of learning sciences throughout the design, development and delivery of instructional solutions. The perspective of “learning design”, “design for learning” and “teachers as designers” indicate that design thinking is the core competence of teachers [12]. Many organizations have proposed frameworks for instructional design competencies [5]. The AECT standards and the IBSTPI competencies are currently the most widely accepted standards for learning design practice. Specifically, in the field of STEM education, the National Institute of Education Sciences has formulated the STEM teacher competency standard, which includes five dimensions, 14 categories and 35 contents. The Dayton Regional STEM Center developed the STEM Education Quality Framework which focuses on the planning and delivery of professional development [13]. These standards are used for curriculum development or teacher evaluation. In Table I, it can be seen that the AECT and IBSTPI standards are well matched to the areas of management, high-level design skills and project housekeeping skills, but not a good fit for the STEM learning design. Not surprisingly, the AECT maintains its standards to provide rigorous guidelines for educational programs aimed at professionals in the educational technology field, and the standards for instructional design produced by IBSTPI publish for general instructors, instructional designer and training managers. The two remaining competency frameworks are STEM specific and most accurately match the key skills required in STEM learning design, with some other competence and a few omissions. This study determined the dimension of discourse coding scheme under the guidance of these competence standards, and designed an evaluation rubric of lesson plan based on the STEM Education Quality Framework.

C. Discourse Analysis for Competence Modeling

Epistemic frame theory suggests that every community of practice has a culture and that each culture has a grammar: a network composed of skills, knowledge, values, identify and epistemology [14-15]. In this study, we consider particular skills and knowledge related to STEM learning design. However, modeling the development of competency through teacher’s design practice is a significant challenge. Epistemic Network Analysis (ENA) provides a quantified approach to analyze the structure of connections in discourse, through observing the co-occurrence of concepts within the conversations during learning [16]. There are four core concepts in the ENA: units, conversation, stanza and codes, and the set of procedures includes identify and defining target codes, devising reliable and valid rules for categorizing discourses and using ENA for analysis. Generating an ENA model from an ENA data should take the adjacency (co-occurrence) vectors from data, compute a dimensional reduction (projection), and calculate node positions in the projected ENA space. ENA moves beyond the traditional frequency-based assessments by examining the co-occurrence structure of codes. It has been successfully applied to analyze collaborative learning and scientific reasoning of pre-service teachers and the design thinking of

the engineering students [17-18]. In this study, learning design competencies was treated as a network of connections among six components (Table II), and ENA was used to investigate the relationships between the components, compare the salient properties of epistemic networks generated by different groups of teachers and explore the development of competencies in different stages of the same teacher group.

III. METHOD

A. Participants

The participants for this study included 33 students from a university in eastern China, who were divided into four types of pre-service teachers, including 9 science teachers, 8 technology teachers, 8 engineering teachers and 8 mathematics teachers. They attended a course called “introduction to the learning sciences” in the fall of 2018 and were invited to participate in the STEM learning design program as a capstone project of this course. All of them had some basic learning design knowledge and ICT skills but they had not any STEM learning design experience.

B. STEM teacher virtual internship system

This study used the STEM virtual internship system to support STEM learning design practice (Figure 1). In the online environment, pre-service teachers worked as interns at a fictitious primary school. The participants were randomly divided into eight groups, each made up of pre-service teachers of science, technology, engineering and mathematics. They had to collaborate on a series of interrelated tasks to design a STEM learning plan, such as selecting a course topic, designing course objectives. During the 12-week internship (2 hours per week), the virtual tutor sent the requirements of each sub-task and related learning resources by email. Participants learn the relevant resources independently and discuss each task with others to complete specific tasks. After group discussion, participants proposed

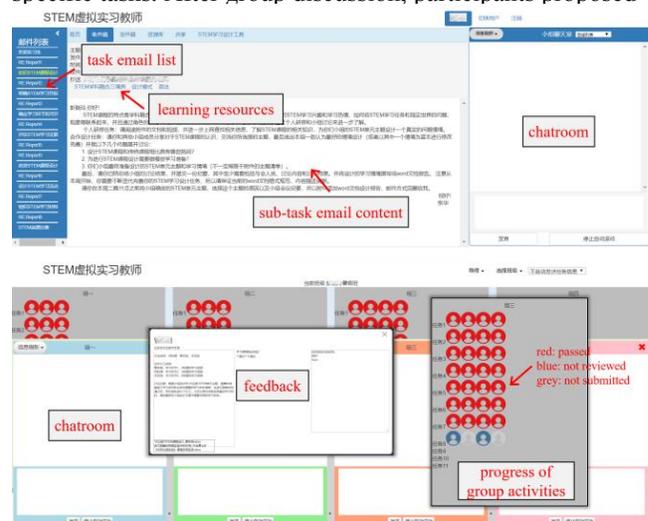


Figure 1. STEM teacher virtual internship system interface (above: pre-service teacher interface; below: tutor interface).

their own lesson plan and submitted to the tutor. In particular, the participants were guided throughout the whole internship by the tutor, including individual learning, regular team meetings. In the last week of the program, participants will present their designed STEM learning plan to their peers and instructor in class.

C. Data collection

All student and tutor actions and interactions are recorded automatically in the log file, enabling us to analyze design process and outcomes. The system automatically records students' (a) STEM lesson plans and other products, (b) conversations with peers and tutors via email and instant message. A total of 9686 utterances and 8 group lesson plans were collected. Based on the review of learning design competence, this study adopted grounded approach to identify six codes from the chat data of online design meetings, which are subject basic knowledge, techniques and methods, thematic context, design of activities, design of products, and objectives and evaluation (Table II). Referring to the STEM Education Quality Framework and STEM Integration Curriculum Assessment [19], a rubric was developed for analyzing lesson plan in this study.

D. Data analysis

For the STEM lesson plans, the two researchers firstly discussed the rubric in detail to guarantee high consistency, and then rated the lesson plans of eight groups independently. The scoring reliability (Cohen's kappa) between the two researchers was 0.77. We used the average score of the two researchers as the final score of each group lesson plans. Those who scored above average were assigned to the high-performing group, while the rest were assigned to the low-performing group.

To identify the elements of the learning design competencies frame as they occur in discourse, we used an automatic coding approach developed by Shaffer, which is called nCoder [20]. The process is (1) defining codes: including a name, a description, and a word list; (2) machine coding: the dataset is automatically coded based on the word list; (3) testing set sampling: a test set is randomly sampled from the coded dataset; (4) human coding: the sample texts are presented to the user for coding; (5) testing: nCoder shows three test numbers: a kappa for the test set, a kappa for the training set (the test items in earlier cycles), and a rho value. And the kappa values measure the agreement between the human coding and the machine coding, the rho shows whether or not the kappa value generalizes to the untested items; (6) merging training data; (7) check disagreement; (8) refining codes: the user remove the disagreements by removing, adding, or refining regular expressions in word list; (8) updating training data. This automated conjunctive keyword coding process has been validated by comparing utterances hand-coded by two independent researchers. Cohen's kappa scores were 0.82-0.96 between the automated system and the human coders and the rho value is less than 0.05, which means interrater reliability of reaching kappa value above 0.65 for all data is statistically significant. After automatic coding, this study performed ENA to analyze the

coded data. The individual were selected as the unit, the chat data of each group in each online design meeting as the conversation, the size of the stanza was set to five, and the six competencies in the coding scheme were selected as the codes.

IV. RESULTS AND DISCUSSION

How do high and low-performing pre-service teachers develop learning design competencies during STEM learning design meetings?

We selected one group from the high-performing groups and one from the low-performing groups according to the score of their lesson plans for ENA analysis, hereinafter referred to as H1 group and L1 group. During the online meetings of STEM learning design, the mean epistemic network of teachers in the H1 and L1 groups were shown in Figure 2. Along the X axis, t-test result shows that there is statistically significant difference between the two groups. Figure 2 showed that the discourse of H1 group was more towards the right part of the ENA space, while L1 group was more towards the left side. To interpret this statistic difference of the centroids of the network according to the network structure, we found stronger connections between *thematic context* and *design of products*, *design of activities* and *design of products*, *design of products* and *objectives and evaluation*, which indicates that high-performing group triggered STEM learning design from describing an authentic learning context, took problem solving as the learning orientation, designed solutions, prototypes or models around the problems or user needs, and emphasized on the assessment of STEM learning outcomes. However, in L1 group, teachers tended to design STEM learning around conceptual understanding and knowledge construction, and activity and evaluation were strongly related to the knowledge contents of subjects.

Specifically, the theme of H1 group is the design of amusement park, which provides the opportunity for students

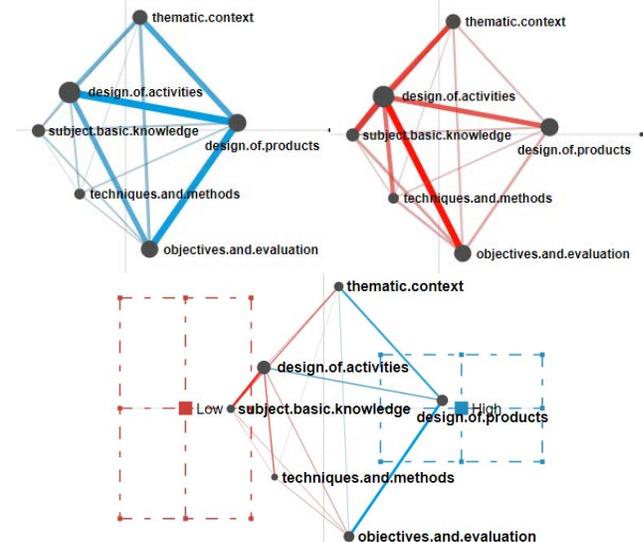


Figure 2. Mean discourse networks of H1 group (left, blue), L1 group (right, red), and a difference network graph

to participate in an open-ended engineering design challenge. Students can use their imagination to build different theme parks, such as Pirate Ship Park, Snow White Park. The course includes crosscutting concepts designed to help students integrate knowledge and skills in science, technology, engineering, and mathematics, such as patterns, causality. And STEM learning experience challenge students to develop higher-order thinking through processes such as demand investigation, exploration of architectural principles, and creation. L1 group's theme is oil and water separation. Although it provides a context related to environmental issues (pollution caused by oil tanker leakage), they failed to design learning in a more student-centered manner. Instead, the instructor of their designed lesson plan will demonstrate relevant experiments, then the students will try to complete the experiment independently, and take a paper-and-pencil test to assessment students' knowledge.

What relationship between pre-service teachers' STEM learning design competence and their lesson plans?

The lesson plan scores of H1 group and L1 group are show in Table 3. In addition to design a context engaging students of diverse academic backgrounds and the degree of mathematical contents integration, the lesson plan scores of H1 group were all higher than those of L1 group. Next, this study divided ten learning design activities into three stages, and analyzed the epistemic network trajectories of H1 group and L1 group in different stages, so as to explore how the trend of design thinking change in the learning design process contributed to the quality of their lesson plans.

TABLE III THE ASSESSMENT OF LESSON PLANS FOR H1 AND L1 GROUP

Assessment dimensions(1-4)	H1 group	L1 group
An Context Engaging Students of Diverse Academic Backgrounds	3	4
An Engineering Design Challenge	4	1
Integration of Mathematics Content	2	2
Integration of Science Content	2	1.5
Quality of Technology Integration	3	2
Degree of STEM Integration	4	1.5
Instructional Strategies and Organization	3	2
Performance and Formative Assessment	3	2

From the average epistemic network graph of H1 group and L1 group in three stages in Figure 3, it can be seen that the learning design features of the two groups are significantly different. The H1 group first identified the expected learning outcomes, then designed the learning context, determined the evidence that could prove that students achieved the expected learning goals, and finally designed relevant activities. However, the L1 group first focused on the learning goal and relevant subject content, followed by the design of learning activities, and finally returned to the evaluation of the original objectives. Despite the tutor's efforts to steer the L1 group to the high-performing group, they have not changed much. These two groups represent two classical learning design patterns, namely, traditional learning design and backward learning design [21]. Combining the content and score of lesson plans, H1 group accurately portrayed lesson plan, tied to multiple

content standards, carried out inquiry activities around interdisciplinary issues, and designed rubric-based, performance assessments that require students to demonstrate knowledge and skill in completing authentic tasks. While in L1 group lesson plan, there were some inconsistencies in learning objectives, activities and evaluations, and the design of activities lack of diversity and challenge. This suggests that L1 group was lack of iterative design process that aligns learning activities with defined goals and expected outcomes.

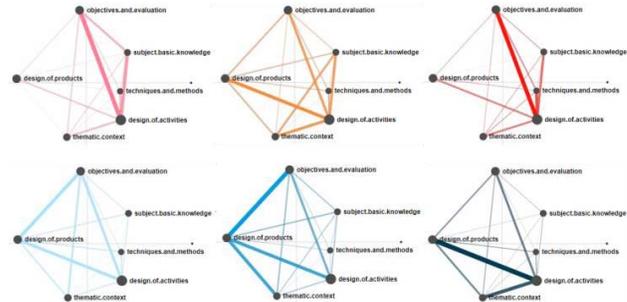


Figure 3. The epistemic trajectory of H1 group and L1 group in the three learning design stages

V. CONCLUSION

This present study used ENA to model STEM teachers' learning design competence, and aligned discourse analysis with lesson plan assessment to explore the characteristics of teachers' design thinking in online design meetings. The findings revealed that the high-performing group designed an open-ended authentic STEM learning experience including crosscutting concepts, encouraged students to develop higher-order thinking through design solutions, prototypes or models to meet the problem requirements, and emphasized rubric-based, performance assessments. They adopted the backward design mode of (a) learning objectives and learning context, (b) learning evidences and evaluation, and (c) learning activities and instructional scaffolds. The low-performing group paid more attention to the connection between disciplinary knowledge and learning activities, whereas learning objectives, learning activities and learning evaluation were not always consistent.

There are many factors that contribute to the quality of STEM learning design outcomes, and there might not be any "gold standard" learning design pattern. But to get a better understanding of STEM learning design, ENA demonstrates the potential to help us model learning design competence and developmental trajectory in STEM learning design context, and to help us analyze how the epistemic network evolution along the design process affects the quality of design outcome. Finally, the findings will support scaffolding learning design in a community of teaching practice and help tutor better stimulate productive discussion in STEM learning design. This study only analyzed the characteristics of pre-service teachers STEM learning design structure in a preliminary stage, lacking detailed and in-depth analysis. In future research, the number of research sample will be further expanded, and we will combine the ENA and

text mining to explore modeling approach of teachers' learning design competence.

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TABLE I VARIOUS LEARNING DESIGN COMPETENCIES FRAMEWORKS

IBSTPI	AECT	National Institute of Education Sciences	Dayton Regional STEM Center
<ul style="list-style-type: none"> • Professional foundations • Planning and analysis • Design and development • Evaluation and implementation • Management 	<ul style="list-style-type: none"> • Design • Development • Utilization • Management • Evaluation 	<ul style="list-style-type: none"> • STEM educational value understanding • Foundation of STEM disciplines • STEM interdisciplinary understanding and practice • STEM curriculum development and integration • Implementation and evaluation of STEM teaching 	<ul style="list-style-type: none"> • Potential for engaging students of diverse academic backgrounds • Degree of STEM integration • Connections to non-STEM disciplines • Integrity of the academic content • Quality of the cognitive task • Connections to STEM careers • Individual accountability in a collaborative culture • Nature of assessments • Application of the engineering design process • Quality of technology integration

TABLE II THE CODING SCHEME OF STEM LEARNING DESIGN COMPETENCE

Code	Description	Example
subject basic knowledge	Competency to integrate knowledge of science, technology, engineering, mathematics	Teachers integrate knowledge of filtration and data analysis into water filtration activities.
techniques and methods	Competency to provide appropriate techniques, tools, and methods	Teachers encourage students to use questionnaires to collect data and use data analysis software to analyze data to determine requirements.
thematic context	Competency to design authentic, ill-structured learning situations	Teacher design a water pollution learning situation to engage students to learn oil and water separation.
design of activities	Competency to design, develop and integrate student-centered learning activities	Teachers design activities suitable for students, such as the collaborative learning, inquiry learning.
design of products	Competency to design scheme, prototype, et cetera to solve problems	Teacher encourage the students to design a prototype of an amusement park.
objectives and evaluation	Competency to design inter-disciplinary objectives and performance-based assessments	Teacher design a rubric to evaluate the students' solutions.