

Using LLMs to Develop Pedagogical Content Knowledge

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Abstract: Large language models (LLMs) such as ChatGPT are particularly effective at taking on personas, supporting powerful, inexpensive, and low-risk simulations for teaching and learning. For example, an LLM can act as a third grade student who has misconceptions about science or fractions. The user can interact with this persona, attempting to guide the virtual student toward new conceptual understandings. Such a use may help pre- and in-service teachers develop pedagogical content knowledge (PCK), expertise that typically requires considerable practical experience. In this paper, we will provide two examples of the use of LLMs for the development of PCK: one in mathematics and one in science. In addition to sharing effective prompts, we will present an analysis of our own conversations with ChatGPT personas, highlighting how the LLM pushed us to think more deeply about the connection between the content and the learner's thoughts and experiences.

Keywords: Large language models (LLMs), pedagogical content knowledge (PCK), role-play, reflection-in-action, reflection-on-action

Introduction

There has been much excitement about the new accessibility to generative AI tools, particularly large language models (LLMs). While much of the conversation has focused on uses for writing, personalized learning, and reducing teacher workload (Herft, 2023; Chan & Hu, 2023), technologies come with specific affordances that sometimes offer possibilities for shifting pedagogies that support new types of learning (Friedhoff, 2008). We decided to explore whether LLMs offered a new and effective way of helping future teachers develop pedagogical content knowledge (PCK) through role play activities. In this paper, we describe our initial experiment with this approach, explain how it supported the development of reflective practice in a unique way, and provide suggestions for applying this type of approach.

Instructors' pedagogical judgments during planning, instruction, and delivery are influenced by resources, which assist them in giving the contents context (Cohen & Ball, 1999). Novel educational strategies could encourage modifications in instructors' understanding of how to teach in a content area more effectively and, in turn, lead to adjustments in their methods of teaching through analysis and reflection. Given the recent wide-spread availability of large language models (LLMs such as Chat GPT 3.5 or Claude, we wondered whether these models could support the development of teacher candidates' pedagogical content knowledge (PCK). In this research we asked an LLM to act as a third-grade student with misconceptions in math and science. We practiced teaching the "student", reflected on our own experiences, and peer reviewed each other's teaching. We were particularly interested in knowledge gains related to teaching a concept using the LLM as collaborator and reflecting on its impact on PCK development.

Literature Review

According to Shulman (1986, 1987), pedagogical content knowledge (PCK) refers to the specialized knowledge required to teach a particular subject area and it encompasses the subject matter knowledge along with the process of transforming that knowledge into a comprehensible form. Several models have been put out to characterize the components of PCK (Appleton 2006; Magnusson et al. 1999; Park & Oliver, 2008).

Literature emphasized that firsthand experience in the classroom is a potent means of learning about teaching and experiences in practice bring about the most significant changes (Lott 2013; Mulholland & Wallace 2001; Munby & Russell 1994; Park & Chen, 2012). Park and Oliver (2008) noted that while receptive learning can affect and increase instructors' knowledge, actual experiences in the classroom have the greatest impact on transformation. They included reflection as a factor that influences the adoption and modification of every PCK element. They also noted that reflection-in-action, the capacity to create and use knowledge during teaching (Schön 1983) and reflection-on-action, making meaning of past experiences to improve future action (Ertmer & Newby 1996; Schön, 1983) were crucial in improving PCK.

Several studies (Mulholland & Wallace 2001; Nilsson 2008) look into PCK development for beginning teachers, and science teachers in particular (Faikhamta & Clarke 2013, Osmond & Goodnough 2011; Wiebke & Rogers, 2014), during preservice education (Wang & Oliver, 2022) and in the transition from preservice to inservice teaching. Existing studies reported several challenges for PCK development such as diverse experiences, worldviews, and levels of epistemological sophistication of teachers in teacher education courses (Beyer & Davis, 2012). Other challenges include lack of modeling classes pertaining to every core curriculum topic (Grossman, 2011), the varying levels of topic-related cognitive load (Aydeniz & Kirbulut, 2014), diverse classroom contexts (Ball et al., 2008), and classroom management strategies (Lott, 2013). Windschitl et al., (2011) stated that teacher education programs provide conceptual tools but do not directly focus on “what to do next in the classroom” (p. 1317). One endeavor towards this issue is creating “praxis tools” to help instructors have conversations about responsive practice (Curry, 2008; Sandoval, Deneroff, & Franke, 2002; Windschitl et al., 2011). Praxis tools “guide planning, instruction, analysis of learning, and reflection” (Windschitl et al., 2001, p. 1317).

This research aims to contribute to the research literature on PCK development for teachers, providing a method for developing PCK with LLMs. This approach offers an innovative tool to practice and develop PCK overcoming the challenge of limited time and experience teachers get to spend in the actual classroom.

Method

As researchers and teacher educators in a Hispanic- and Minority-Serving Institution in the Southwest borderlands of the USA, we have observed the need for developing methods and opportunities for teachers to have ample practice opportunities for PCK development. As an initial step in exploring the possibilities of how an LLM might support PCK development, we each developed role-play prompts to address a student misconception. We recorded ourselves experimenting with these prompts, recording our screens, and using talk-aloud procedures to document our thoughts. We then reviewed both our own and each other's recordings, commenting on observations. Finally, we analyzed our notes into thematic elements that explored the limitations and possibilities of the approach. Before presenting our analysis, we briefly describe each of our individual role play experiences. Two of the prompts we used in our research are below.

Example 1: 3rd Grade Student Learning Fractions

The first role play examples focused on a 3rd grade student learning fractions. Melissa used the following prompt:

You are a 3rd grade student who is notably stubborn in their beliefs about fractions, often having a hard time being convinced otherwise. This stubbornness is reflected in consistently incorrect responses and a reluctance to accept correct explanations easily. You require extensive clarifications, patient guidance, and

repeated explanations to gradually shift your understanding. Your responses are brief and typically reflect its strong, albeit incorrect, convictions about fractions. You focus strictly on fraction-related topics. After eventually grasping the correct concepts, you provide feedback on the teaching, especially noting the effectiveness of the explanations in overcoming its stubborn misunderstandings.

I will be the teacher. Start by telling me a multiplication fraction problem you don't understand and I'll try to help you understand it. This is so that I can practice my teaching skills. Please keep talking like a 3rd grader who doesn't understand fractions.

Example 2: 3rd Grade Student Learning about Phases of the Moon

The second role play examples focused on a 3rd grade student who has a misconception about the phases of the moon. Suparna used the following prompt:

You are a third grade student who has a misconception about the cause for the phases of the moon. You consistently provide incorrect reasonings and find it difficult to accept the correct explanation easily. You need guidance through clear and repeated explanations to understand the correct reasons. You provide short incorrect responses based on your firm beliefs and strictly focus on the topic of the phases of the moon. When you finally understand the correct concept, you provide feedback on my teaching, especially how effective my explanation was in overcoming the misconception.

I will be the teacher. Tell me what you understand about the phases of the moon as a third grade student, start by asking a question. I will try my best to clarify and help you understand. I want to do this so that I can practice my teaching skills.

Findings

Our analysis of our conversations and thought patterns highlighted three primary themes: uniqueness of the LLM, scaffolding, and the importance of reflection which are discussed below.

Although many teacher educators use peer-to-peer role play to practice teaching and even for PCK development, there were several unique characteristics of doing so with an LLM. The uniqueness is not necessarily better or worse than peer-to-peer role play, but the experience offers unique affordances to traditional approaches. We focused on five unique elements of practicing with an LLM: enhanced thought, improved content explanation, time and repetition, natural scaffolding, and generic and specific feedback.

First, throughout our conversations, we noticed that the LLM seemed much more effective at expressing its thoughts and ideas than the typical 3rd grade student would. This could be both a weakness and a strength of this approach. Although it could give a false impression of how students would actually react to instructor questions, it also provides more insight into the type of thinking students might be engaged in or confused about. This leads to our second type uniqueness—improved content explanation. The LLM often provided a clearer explanation of the content itself, again better than a typical learner, but did so using child-friendly language and terms. This process could provide future teachers new ideas for providing simple explanations and examples that they can draw on in future teaching experiences. It also pushes the instructor to think of the content from different angles and even enhances content knowledge.

Our third area of uniqueness focuses on time and repetition—engaging in these role plays involves very limited risk and cost. It allows for repetition on a specific area of practice both in groups and individually. Fourth, we noticed that the key to our success was our learning in the role plays was centered on the thoughts we had both during and after our role plays. Reflection during and after our experiences were key to how we came to understand the conversations. The benefit of having time to think through each response, attempting to understand the student's

comments and coming up with an appropriate question to continue the conversation, strongly improved our learning experience. Of course, we came to the practice with more experience than a typical teacher candidate, both having taught in our respective content areas (math and science), and we wondered whether this made a difference in our experiences. We hypothesized that scaffolding may be critical in supporting this type of reflection with future teachers, perhaps practicing these role plays with a class and small groups before engaging individually and emphasizing careful reflection throughout the process.

Finally, one of the greatest benefits of this practice over regular peer-to-peer conversations is the potential for receiving feedback at the end of practice. In our examples, we noticed that initial feedback seemed quite generic, often getting the same feedback every time. However, probing for more detail through specific requests to highlight advice for improvement or specific examples of questions we could have asked led to higher quality.

Discussion

Developing teaching skills through role play is not new; many teacher educators ask students to practice with each other, with some students acting as students. Such a practice is important and incredibly useful, as the future teacher must try to think like the student. Role play with LLM offers support for a slightly different skill—it supports reflection both during (reflection-in-action) and after (reflection-on-action) the experience (Schön, 1986), which has been closely connected to design-based learning (Warr & Mishra, 2023)

Reflection-in-action describes what happens during an event that can still make a difference in the outcome—it “is bounded by ‘action-present, the zone of time in which action can still make a difference to the situation” (Schön, 1983, p. 62). The power of reflection-in-action is that it supports trying something, seeing the result, then making adjustments, each time constructing a “theory of a unique case” that can be solved interactively (Schön, 1983, p. 68). This practice is the heart of design: designers put something out in the world, consider the result, then revise, all in an integrated and fluid manner (Pendleton-Jullian & Brown, 2018). A design approach to learning has been demonstrated to develop actionable knowledge that is specifically designed to meet a purpose (Perkins, 1986). In other words, rather than learning about something, a design approach to learning supports learning for something, and the result is knowledge that is specifically molded to the purpose of accomplishing that task. This type of knowledge becomes integrated into professional practice, supporting effective action (Schön, 1983). Reflection-on-action describes reflection back on an event (Schön, 1986). Although changes cannot be made to the situation, learning from what has occurred supports changes in future practice. It further integrates actionable knowledge into ways of acting and being (Schön, 1986).

Reflection-in-action is supported by Generative AI role-play activities because of the ability to pause between each term, discussing and thinking about what has been said and what a useful next turn might be. The process can be modeled by an instructor or experienced teacher, setting forward the type of reflective practice that has been shown to continually develop effective pedagogy. The feedback given by the LLM (if used critically) can support reflection-on-action, where participants review the conversation and can identify areas where they could have improved as well as moments when they might have missed a misconception or other idea. And, because of the low-risk ability to repeat exercises over and over, the knowledge developed through the reflection-on-action can immediately be applied forward to another example, a way of “making sense of things” (Krippendorff, 2005) and developing actionable knowledge.

This type of learning with LLMs is not limited to this specific role play example; any response we get from an LLM can serve as a reflection and discussion point, but making a habit of this type of reflective practice needs to be supported and practiced. In the future we want to study and discuss principles we can develop after completing the analysis that can effectively support the application of using LLMs for learning.

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