Reported Impact of Specialized Courses on Pedagogical Content Knowledge Development of Mathematics Education Program Candidates' transition to First-Year Teachers

Nicole Hersey, Ph.D
University of Rhode Island
ndhtennis@uri.edu
712 Chafee Hall
Kingston, RI 02881
(401)864-5191

Cornelis de Groot, Ph.D
University of Rhode Island
degrootc@uri.edu
709 Chafee Hall
Kingston, RI 02881
(401)874-4149

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Abstract

This paper discusses findings of a formal investigation into the impact of specialized courses on the development of pedagogical content knowledge of teacher candidates pursuing certification to teach mathematics in secondary schools. This study is two-phased, with phase I beginning in the final year of participants' teacher preparation program and phase II during the first year of teaching with a subset of phase I participants. The study investigates the development of beginning secondary mathematics teachers' pedagogical content knowledge (PCK) about teaching and learning mathematics over this two-year period. Data were compiled from multiple sources: a researcher created PCK inventory, interviews, classroom observations, and an exit survey. Each source provided information for understanding how beginning secondary mathematics teachers developed their PCK and insight into participants' perceptions of their development.

Findings from this study indicate that PCK developed through its explicit integration in the specialized courses. Participants were given assignments and opportunities to connect their Content Knowledge (CK) and Pedagogical Knowledge (PK) and begin transforming these types of knowledge into PCK. The role of self-reflection and collaboration with others was also found to be instrumental in PCK development. Having opportunities to develop all aspects of knowledge was not always available for participants in all situations. At times, there were PCK tasks that were beyond to scope of the given experience or participants were limited in their freedom to exercise their knowledge. This data demonstrates that participants needed opportunities and the agency to act on those opportunities to develop their PCK.

Introduction

Research has shown that teachers have different types of knowledge that impact their effectiveness as practitioners. However, some have posited that teachers are inadequately prepared to enter the classroom through a variety of teacher preparation programs (Darling-Hammond & Youngs, 2002). These reservations are also noted about beginning secondary mathematics teachers' preparedness to enter the profession (Schmidt, Burroughs, Cogan, & Houang 2016). In the case of the preparation of mathematics teachers, there has been a long-standing focus on content knowledge development, in alignment with ATE standard 1 (ATE, 2008). Nevertheless, having a strong knowledge base in mathematics is not the only type of knowledge necessary to become a teacher (Hill, Schilling, & Ball, 2004; Monk, 1994). Currently, there is a gap in the literature about how secondary mathematics teachers develop their knowledge for teaching, known as Pedagogical Content Knowledge (PCK), during the transition from pre-service to in-service teaching. Understanding how this knowledge develops and individuals' perceptions of their development has implications for teacher preparation programs and school leaders. Thus this study aligns to ATE standard 4, professional development, and standard 6, program development (ATE, 2008).

Literature Review

Shulman (1986) defined *pedagogical content knowledge* (PCK) as the specialized knowledge possessed by teachers beyond pure content knowledge (CK). According to Stevens, Harris, Aguirre-Munoz, and Cobbs (2009) this specialized knowledge is comprised of knowledge of: (a) what it means to teach a particular subject, (b) instructional strategies and representations for teaching particular topics, (c) students' understanding and potential misunderstandings of a subject area, and (d) curriculum and curricular materials. Since researchers have found mixed results of the effects of teacher preparation programs on the

development of PCK (Goldhaber, Liddle, & Theobald, 2013; Grossman, 1990; Leong, 2013; Saeli, Perrenet, Jochems, & Zwaneveld, 2012; Schmidt et al, 2016), there is a need to investigate the role of preparation programs and practices on teachers' ability to teach mathematics. Similarly, there is a need to understand what experiences and factors influence PCK development and how it develops over the first year(s) of teaching. This will help guide teacher educators and policymakers in decisions on program and practice. Therefore, teacher educators need to be more informed about what specialized knowledge teachers need in order to better prepare pre-service teachers for their transition into the profession (Cummings, 2010).

It is a common assertion that teachers' content knowledge development becomes relatively dormant after graduating from their preparation programs unless teachers actively work to continue their development. Kleickmann et al. (2013) summarize this phenomenon by stating "the inservice phase does not seem to contribute to substantial further development of CK after initial teacher education" (p. 100). Instead, teachers tend to focus on their grades' or courses' content and become less confident or comfortable with other areas.

The purpose of this two-phased study was to investigate the self-reported and observed development of beginning secondary mathematics teachers' PCK over the course of the final year in their preparation program (phase I) and the first year of teaching (phase II). The following research questions were addressed:

1. How do secondary mathematics teachers describe the development of their PCK before and during their first year as a teacher?
2. What experiences and factors influence the development of secondary mathematics teachers' PCK during this period?

We examined the development of seven program participants in phase I and a subset of three of these participants in phase II to shed light on program experiences that either supported or hindered their PCK development. These experiences included the following specialized coursework: a mathematics capstone course, a mathematics methods course, and a mathematics curriculum course. These courses were completed in the fall semester of their final year in the program, which included a practicum with the cooperating teacher(s) with whom they would be student teaching in the spring semester.

Methodology

Taking into account the concerns about beginning secondary mathematics teachers' preparedness to enter the profession and the gap in the research on PCK development during the transition from pre-service to in-service teaching, we conducted a qualitative study. Data were compiled from multiple sources at selected transition points in both the teacher preparation program experience and subsequent work experience (see Figure 1): PCK inventory instrument, interviews, classroom observations, and an exit survey.

	Phase I: All seven participants									Phase II: Kara, Molly, & Alyssa									
Setting	Pre-Student Teaching				Student Teaching					First Year Teaching									
Month	S	O	N	D	J	F	M	A	M	S	O	N	D	J	F	M	A	M	J
Data Collection Procedure																			
Demographic Survey	X									X									
PCK Inventory	X			X				X		X						X			
Interview		X						X				X						X	
Observation												X						X	
Exit Survey																			X

Figure 1. Timeline of Data Collection.

Each data source provided information for understanding how beginning secondary mathematics teachers developed their PCK and their perceptions of their development. A PCK inventory for secondary mathematics teachers was not available. By adapting items from Sultan and Artzt

(2011), a researcher-designed PCK inventory instrument was developed. In addition, the Learning Mathematics for Teaching (LMT) Project (Hill, Ball, & Schilling, 2008), an investigation of elementary education teacher PCK development, was used as a model for constructing this inventory. Interviews in both phase I and phase II were semi-structured and audiotaped. The design and content of the interviews were to elicit descriptions of experiences and beliefs about PCK development. Two classroom teaching observations occurred in phase II once at the beginning and once toward the end of the school year. In the observations, critical attention was paid to instances where participants enacted specific teaching tasks of PCK. Observations facilitated the examination of the congruence between participants' beliefs about teaching and their teaching practices. Participants' perceptions about the factors influencing their PCK development were also gathered through an exit survey that includes multiple-choice questions (Cummings, 2010).

Participants' responses to interview questions, field notes from observations, and the PCK inventory responses were coded and analyzed for initial themes (Auerbach & Silverstein, 2003). Participants' results from each administration of the PCK inventory instrument were compared to their subsequent or previous results. In addition, the same analysis process described for interviews and observations was utilized to label codes and identify themes within the PCK inventory responses.

Participants

In this study, the teachers of interest were the graduates of a preparation program who did their student teaching in the spring of 2017 and started their first teaching jobs in August of that year. They were secondary education or elementary education majors who earned middle school extensions in mathematics to their respective licensures. Participants were recruited from the

2016-2017 cohort at a university in the northeast, consisting of seven secondary and four elementary mathematics PSTs. Of this group, six secondary and one elementary mathematics PSTs participated in phase I. A subset of three participants of the phase I group continued in phase II. A summary of the participants is presented in Table 1 below.

Table 1
Summary Table of Participants

Participant (Pseudonyms)	Gender	Program	Early Admission Program	Noyce Scholar
Ben	Male	Undergraduate; Secondary Education	Yes	Yes
Emma	Female	Undergraduate; Secondary Education	Yes	
Hannah	Female	Graduate; Secondary Education	N/A	Yes
Lisa	Female	Undergraduate; Secondary Education	Yes	
Kara	Female	Undergraduate; Secondary Education	Yes	
Molly	Female	Undergraduate; Secondary Education	Yes	Yes
Alyssa	Female	Undergraduate; Elementary Education	Yes	

The Coursework

The participants entered the preparation program in their junior year as undergraduate students or their first year as graduate students. The professional coursework consisted of a four-semester developmental sequence culminating in student teaching during the final semester (Figure 2). The specialized courses discussed here fell in the third semester of the sequence, the pre-student teaching semester.

<table>
<tr><th>Education</th><th>Mathematics*</th></tr>
<tr><td>Semester 1</td><td rowspan="3">Calculus I
Calculus II
Calculus III
Linear Algebra
Mathematical Rigor
Abstract Algebra
Geometry
Number Theory
Discrete Mathematical Structures
Probability & Statistics</td></tr>
<tr><td>Educational Measurement
Middle School Methods
Practicum 1</td></tr>
<tr><td>Semester 2</td></tr>
<tr><td>Literacy in the Content Areas
Special Needs
Practicum 2</td><td></td></tr>
<tr><td colspan="2">Semester 3 Pre-Student Teaching</td></tr>
<tr><td>Classroom Management
Methods
Pre-Student Teaching Practicum</td><td>Math Capstone Course
Math Curriculum Course</td></tr>
<tr><td colspan="2">Semester 4 Student Teaching</td></tr>
<tr><td>Student Teaching Seminar
Student Teaching</td><td></td></tr>
</table>

Figure 2. Education and Mathematics Program Overview.

One of the specialized courses is a capstone mathematics course. This course is taken concurrently with the methods course, of which there is one for secondary education majors and a different one for elementary education majors. Secondary education majors also take a course focused on secondary mathematics curriculum. In the capstone mathematics course, connections are made among concepts covered in college-level mathematics courses required for certification and with content taught in secondary and middle schools. There are specific assignments and experiences in which the pre-service teachers develop an awareness and understanding of how they think about different topics and become more proficient in their content knowledge (CK) as well as tasks of PCK. In this way, teachers develop a deeper understanding of the mathematics that they teach in grades 7-12. This class was added to the requirements for secondary education mathematics candidates after surveying graduates of the program from past years. These

graduates expressed that they felt comfortable with knowing mathematics for themselves and general pedagogy but where anxious about what they would be teaching in their profession.

Alongside the math capstone course, secondary mathematics teacher candidates take a curriculum course and their mathematics methods course. In the curriculum course, assignments center on auditing current curriculums and curricular materials, and discussing teaching and navigating best practices within those curriculums. The methods course focuses on instructional practices, which have been found to promote conceptual understanding with learners. Teacher candidates practice designing lessons using inquiry approaches to mathematics instruction. In addition, the use of technology in instruction is a focus of both the curriculum and methods courses. The three courses work in conjunction with one another to promote PCK and CK development.

Data Analysis

With a qualitative approach, participant responses to interview questions, field notes from observations, and the PCK inventory responses were coded and analyzed for initial themes (Auerbach & Silverstein, 2003); "data analysis occurs alongside data collection" (Galletta, 2013, p. 119). In order to do so, the audio recordings of the interviews were transcribed. Next, both interviews and field notes were read in their entirety. Upon a second reading, the researcher looked for meaningful sections or units pertaining to participants' experiences and PCK development. These meaningful sections were analyzed and coded. Themes emerged by looking for "patterns across interviews and across other data sources" (Galletta, 2013, p. 125). Lastly, the raw data was revisited and participant checking was utilized to distill interpretations of both the essential meanings and the general structure.

Responses to the items on the PCK Inventory were analyzed in two phases. The first phase looked at the correctness and appropriateness of participants' responses to the different questions. The second phase of analysis looked for trends in responses to determine if there are similar aspects of knowledge present among the participants. Participants' results from each administration of the PCK inventory instrument were compared to their subsequent or previous results. This illustrated to what extent the participant's PCK changed over time. In addition, the analysis process described for interviews and observations was utilized to label codes and identify themes within the PCK inventory responses.

Exit survey responses were analyzed to determine if trends occurred between participants' experiences and participant-selected factors. Specifically, participants' identification of which experience(s) they believe were influential to their understanding of how to teach mathematics were of interest.

To help uncover themes, we used MindMup (https://www.mindmup.com/), a mind mapping application that can link to other documents. This allowed us to group condensed text from interviews and observations into codes and themes and facilitated analysis. Lastly, the raw data was revisited, and participant checking was done to check interpretations of both the essential meanings and the general structure. In participant checking, participants were sent excerpts of the synthesized data and findings for feedback on whether their experiences, feelings, and thinking were accurately and fully represented.

Results

Findings from this study indicated that PCK developed primarily from participants' experiences working with students, thus showing the interaction with real students over a prolonged period of time interchanged with coursework is crucial to this development. This

finding is in alignment with ATE's Standards for Teacher Education regarding professional development (Standard 4). This is in line with the Realistic Teacher Education, which highlights the need for interaction between theory and practice as interwoven elements rather than separate elements (Korthagen, 2004; Korthagen, Kessels, Koster, Lagerwerf, & Wubbels, 2001).

Participants' descriptions of their PCK development

In addition to working with students, participants identified particular program elements that contributed to their development including the specialized courses they completed. The professional coursework consisted of a four-semester developmental sequence culminating in student teaching during the final semester. The program design gives candidates a gradual increase of responsibilities and includes practicum experiences integrated with their theory courses [ATE Standard for Teacher Education, Standard 5] (ATE, 2008). In addition, the specialized coursework was integrated into both the education major and mathematics major to further develop candidates' CK and PCK; this will be discussed further in this paper.

Coursework and their identity. Developmentally sequenced and integrated coursework provides ample opportunities for participants to become aware of and develop their beginning teacher identity. In the mathematics capstone course, connections are made among concepts covered in college-level mathematics courses required for certification and with content taught in high schools and middle schools. There are specific assignments and experiences (see Figure 2 below) in which PSTs develop an awareness and understanding of how they think about different topics and become more proficient in their content knowledge (CK) as well as tasks of PCK in the domains of Knowledge of Content and Teaching (KCT), Knowledge of Content and Student (KCS), and Knowledge of Content and Curriculum (KCC). In this way, they develop a deeper understanding of the mathematics that they teach in secondary classrooms.

Alongside the math capstone course, PSTs take a curriculum course and a mathematics methods course. In the curriculum course, assignments center on auditing current curriculums and curricular materials, and discussing teaching and navigating best practices within those curriculums. The methods course focuses on instructional practices. Participants practice designing lessons using student-centered inquiry approaches to mathematics instruction. In addition, the use of technology in instruction is a focus of both the curriculum and methods courses. Kara explained how the specialized courses helped her start to connect her CK, PK, and PCK:

> I think the more specialized courses my senior year were the most helpful, when you take classes with just math education majors. I feel like those were really helpful because, again, I learned the different tools- about Desmos and these videos and stuff like that. It's more geared towards math and teaching math since some of the other classes I took I felt like okay, I can see how this fits in English, but I don't really know how I'm going to apply this to my own teaching. So mostly just all my classes senior year, those classes with our advisor that were specialized and the math capstone class, that was also just specialized with just math education and you learn about the math and the education piece put together. [Kara- Interview 3]

The three courses work in conjunction with one another to promote the transformation PK and CK into PCK as illustrated in Figure 3 below.

Course	Course Assignments	Associated PCK Tasks	
Math Capstone Course	Mini Lesson Presentations	KCT	Design of Instruction Sequencing of Topics* Selection of Examples* Evaluate Different Representations of Topic Use of Questioning
		KCS	Anticipate Student Thinking* Anticipate Potential Areas of Confusion or Difficulty* Ways to Motivate Students Hear and Interpret Students' Thinking
		KCC	Program/Instructional Materials*
	Resource Evaluation	KCS	Anticipate Student Thinking* Anticipate Potential Areas of Confusion or Difficulty* Ways to Motivate Students
		KCC	Vertical and Lateral Curriculum Program/Instructional Materials*
	Homework Assignments	KCT	Selection of Examples* Evaluate Different Representations of Topic Use of Questioning
		KCS	Anticipate Student Thinking** Anticipate Potential Areas of Confusion or Difficulty*
Math Curriculum Course	Textbook Audit Curriculum Map Investigation	KCT	Sequencing of Topics*
		KCS	Ways to Motivate Students
		KCC	Vertical and Lateral Curriculum Program/Instructional Materials*
Math Methods Course	Unit Plan	KCT	Design of Instruction Sequencing of Topics* Selection of Examples* Evaluate Different Representations of Topic Use of Questioning
		KCS	Anticipate Student Thinking* Anticipate Potential Areas of Confusion or Difficulty* Ways to Motivate Students
		KCC	Vertical and Lateral Curriculum Program/Instructional Materials*

Figure 3. Course assignments and associated PCK tasks.

While completing their final semester of coursework prior to student teaching, participants explained that they felt comfortable with their higher-level content knowledge (CK) and pedagogical knowledge (PK), but that they needed earlier experiences with the content they would actually be teaching in their classrooms (PCK). This indicated a lack of integration between CK and PK prior to the last year in the program. Having opportunities to develop all

aspects of knowledge was not always available for participants in all situations. At times, there were PCK tasks that were beyond to scope of the given experience or teachers were limited in their freedom to exercise their knowledge. This data demonstrated that participants needed opportunities and the agency to act on those opportunities to develop their PCK. Participants felt the specialized mathematics courses allowed them to explore the tasks of PCK while also making connections between their content knowledge and the knowledge they needed to be effective teachers. For instance, Molly explained how the math capstone course

> I think that the math capstone course has been great this semester and huge in making connections between the courses we've taken and what we're going to teach. I'm so glad we have that course. I've made a lot of connections from the capstone into my other courses too. I'm never going to teach directly Abstract Algebra in a classroom, so I don't have a huge understanding of it. I just think some of the higher-level math classes, and we've taken so many higher-level math classes, and I guess the thing I kind of wish is that we had a course like this earlier where we could make those connections directly to how we're going to be teaching. Because I've always wondered when I'm ever going to use advanced probability in my classroom, for example. I know I will but some of the stuff I question if I will. [Molly- Interview 1]

Programs could consider integrating specialized mathematics courses or increasing the number of courses to facilitate PCK development.

Experiences and Factors Influencing PCK Development

Knowledge Development. Throughout the two phases of this study, participants developed CK, PK, and PCK alongside one another. The development of CK, in particular, supported the development of PCK tasks. This study largely confirmed findings from Kleickmann et al. (2013). Specifically, we found that having deeper content knowledge contributed to how participants were able to construct and effectively use examples, answer student questions, evaluate resources, and use precise mathematical language. As with Kleickmann et al. (2013), teachers' CK development plateaued once they entered the field, while PCK continued to develop during the student teaching period and the first year of teaching.

However, findings from this study demonstrate that teachers need to employ their content knowledge for many tasks of PCK, thus it is crucial for them to continue to develop their CK concurrently with their PCK. This is an important finding for designers of professional development activities as this implies that opportunities for CK development need to be available longitudinally.

Program influence. The organization of the program as well as specific program elements were highlighted by participants' throughout both phases of the study. Notable, participants' development illustrated the importance of interactions with real student over prolonged periods of time interchanged with coursework, as done in their practicums and student teaching. Having opportunities to implement their ideas about teaching and learning coupled with spaces and time to discuss with peers and their instructors shows how there needs to be continuous interaction between theory and practice (Korthagen, 2002). Alongside the interwoven elements of practicum and theory, participants identified their specialized coursework as a place where their CK and PCK further developed largely in parallel. Thus, programs, including ours, need to strive to begin this connection between CK and PK much earlier in their course sequences.

Teacher identity. As discussed previously, participants PCK development and teacher identity development was closely associated with the developmentally sequenced and integrated coursework. Initially, participants focused on PCK tasks that they viewed as central to the role of a teacher, such as designing instruction, selecting examples, use of questioning, hearing and interpreting student thinking, and identifying ways of motivating students. As student teachers, the participants gradually began to view themselves as "the teacher." They began to have confidence in their competencies since their identity as a teacher became clearer. With believing

they possessed the status of a teacher (Korthagen, 2004), participants expanded their focus to additional PCK tasks, including anticipating student thinking, selecting instructional materials, and sequencing of topics. Thus, the different types of knowledge being developed through their preparation program are intimately tied to their developing teacher identities; they began to view themselves more as teachers and less like students-of-teaching. Teacher preparation programs should not underestimate the importance of addressing the development of beginning teacher identities as tied to PCK development. Our findings demonstrate that activities specifically targeting teacher identity development also contribute to the development of PCK. One of the most important findings is that the development of a reflective capacity is paramount to the continued growth of teacher identity in the first year of teaching of the participants.

Influence of the field. Participants explained that they experienced a sense of unfamiliarity with many aspects of teaching during student teaching and the first year of teaching, including the curriculum, content, and population. Often, they tried to map new experiences onto previous ones, which primarily consisted of the kind they had when they were students themselves. Participants indicated that colleagues can ease the feeling of unfamiliarity by assisting beginning teachers in planning, sharing resources, and modeling reflective practices.

Participants compared themselves to more experienced teachers and mirrored some of their behaviors. Participants identified colleagues or other school professionals as resources that facilitated their instructional design, aided in selecting program materials, promoted development in their curricular knowledge, and enhanced their knowledge of their students. In particular, they felt support in their development of anticipating student thinking and potential areas of confusion or difficulty. This was especially true for Kara, who was afforded an induction coach in her first year of teaching. This finding is consistent with findings from Marable and Raimondi (2007),

who explained that peers are the main source of support when there are no formal mentors assigned.

Not all interactions with colleagues enhanced the participants' PCK development since some of their beliefs or practices learned during their teacher preparation program deviated from the schools'. This caused some tensions for participants as they had to renegotiate aspects of their professional identities (Eteläpelto, Vähäsantanen, & Hökkä, 2015). For example, some of their beliefs about how the curriculum should be arranged were left unemployed. While they became knowledgeable about the prescribed curriculum, they did not have many opportunities to fully enact their curricular knowledge related to sequencing of topics.

Participants possessed competencies but they did not yet have agency and perceived status or competence to enact some of their beliefs. Lack of status and confidence as a first-year teacher also directly impacted their PCK development as self-confidence is considered a precursor for PCK development (Van Driel & Berry, 2010). One of the important findings of this study is that participants need to be empowered by schools to employ their developing professional knowledge.

Reflection. It is well known that teacher candidates' reflective abilities are an essential skill that needs to be nurtured and practiced (Darling-Hammond, 2006; Korthagen, Loughran, & Russell, 2006; Loughran, Brown, & Doecke, 2001). During their preparation program, participants explained how reflection was integrated into their practicum experiences and methods course. This core component of their methods course directly connects to ATE Standards for Teachers Education, specifically standard 4 (ATE, 2008). They continued to utilize the ALACT process of reflection (see Korthagen, 2002) during their first year, though they

explained they sometimes had difficulty in setting aside time to do so. The pace of schools does not allow for active reflection by teachers.

Having multiple opportunities to work with students and reflecting on those experiences contributed greatly to participants' development in multiple tasks of PCK concurrently. Many times participants did not realize they were learning or developing in the different tasks of PCK and only by reflecting on their past experiences did they become cognizant of their growth. This is in line with findings from Korthagen (2017) who explains that teacher learning happens as the teacher experiences different occurrences and through reflection on those experiences:

An important finding of this study is that these participants learned to systematically reflect on-action and in-action during their preparation program, which provided explicit opportunities and instruction for it. However, the participants who were first-year teachers were too overwhelmed with establishing their status as a teacher to employ these types of reflection systematically albeit rather incidentally.

Concluding Thoughts and Implications

While this study had a small number of participants, these participants are representative of others like them. There are many PSTs that have similar experience as these participants. Understanding their development within specific tasks and what supported or hindered it may shed light on how others also develop. While this study is not generalizable to other situations, the descriptions of the participants and their experiences can facilitate transferability as others recognize their own students in our participants. The findings of this study contribute the experiences and perspectives of these participants to the field and the study addresses the gap in the literature about the transition of teachers from pre-service to in-service with focus on changes in PCK.

Some important takeaways from this study include: 1. Programs need to make the connections between CK and PK much earlier in their courses and programs; 2. Developing CK, PCK, and PK in unison promotes the development of all three concurrently rather than "unlearning" as Molly phrased it; 3. Teacher education programs and schools should consider providing time, places, and coaching for beginning teachers to systematically reflect as this will greatly contribute to their growth in PCK tasks; and 4. Effective professional development opportunities include a focus on continued CK development alongside PCK development.

In our program we have been working for some time on takeaway two and three but were surprised by takeaway one. This finding implies that the relationship between the mathematics department and the secondary education department must be suitable to address such a need of teacher candidates. We clearly have work to do.

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