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THE EFFECTS OF PHYSICS TEACHERS' PEDAGOGICAL CONTENT KNOWLEDGE ON STUDENTS' ATTITUDES TOWARD PHYSICS AND THEIR ACHIEVEMENT

Shovan Ghosh[1]
Dr.Manu Sigh[2]

Research Scholar, Department of Education ,Sunrise University[1]
Professor, Department of Education, Sunrise University[2]

Abstract

One of the main goals of physics teaching is to increase students' interests and achievements in physics. A teacher has an important role in designing, planning, and implementing a lesson (Hashweh, 1987; Kinskey & Zeidler, 2021; Njiku et al., 2021; Ozden et al., 2013). Researchers have agreed that teaching is one of the most influential factors that affect student achievement (Kim et al., 2019). Goldberg (2001) and Guskey (2003) have underlined that highly qualified teachers affect students' learning. Researchers (Gess-Newsome & Lederman, 1999; Shulman, 1987) have emphasized that the main criterion for successful teachers is to have a solid knowledge base that includes a mixture of content knowledge and pedagogical knowledge or knowledge for teaching.

Key WordS: physics, achievement, pedagogical knowledge

Introduction

In the second half of the 1980s, Shulman (1986 & 1987) claimed that teachers transformed their knowledge to teach in the classroom context and indicated a need to understand how a teacher transformed their content knowledge into teaching in the classroom. Pedagogical content knowledge (PCK) is defined by Shulman (1986 & 1987) as a blend of content and pedagogy concerned with understanding how topics are effectively taught, organized, and presented in the classroom. Since Shulman's defining the PCK, many research studies have been conducted to understand teachers' PCKs and how the content knowledge transforms into teaching in the classroom (Gess-Newsome & Lederman, 1999). Research on the PCK of physics teachers has shown that teachers who possess similar content knowledge can implement a specific topic for students in different ways. Researchers have suggested that these differences stem mainly from teachers' PCKs (Hashweh, 1987; Käpylave et al., 2009). Researchers have also indicated that the teachers' PCKs have a much more complex structure from this perspective. Because of this reason, scholars (Gess-Newsome & Lederman, 1999; Kutluca & Mercan, 2022; Loughran et al., 2001) have suggested that more than a single method is required to evaluate teachers' PCKs. The researchers also state that using the multi-method in PCK assessment helps assess the complex structure of transforming a teacher's knowledge into the teaching process. For example, Louhgran et al. (2004) suggested that topic-specific studies are needed to understand how teachers transform their knowledge to teach while teaching a specific physics topic.

Given the complex nature of teachers' PCK, researchers have suggested that there is always a need to conduct new research studies to understand better the subject-specific nature of physics teachers' PCKs (Ekiz-Kiran et al., 2021; Tufail, 2021). With this aspect, most studies have focused on the PCKs of preservice and in-service physics teachers. However, the number of studies conducted with in-service physics teachers is very small compared to those undertaken with n preservice physics teachers (Frågåt et al., 2021). Although many studies have examined physics teachers' PCKs (for example, Kutluca, 2021; Shin & Song, 2021), very few studies have studied the differences between physics teachers' PCKs and their students' achievements and attitudes. Also, very little research has examined how the teaching experience of physics teachers influenced the PCKs of novice and experienced teachers.

For example, Lin (2017) focused on the difference between experienced and preservice elementary physics teachers' content knowledge and PCKs. Results showed that the experienced had more content knowledge with higher confidence than preservice teachers. However, there were no statistical differences between the experienced and preservice teachers in predicting the students' preconceptions about the topic. In another study, Goes, Fernandez & Eilks (2020) examined the PCKs of prospective and in-service teachers. Their results revealed that teaching experience caused differences in the PCKs of teachers. According to their findings, experienced teachers had a more advanced repertoire of instructional strategies. In their study, preservice teachers focused on traditional and content-focused approaches, while experienced teachers considered the application of the content. In a recent study, Gao et al. (2021) examined the interactions among the PCK components of middle school physics teachers. Their research revealed that instructional strategies and physics content knowledge were most frequently connected with other PCK components. Abukari et al. (2022) assessed physics educators' PCKs and the impact of their PCKs on their students' PCK development. Results revealed that educators' PCKs had a very strong positive influence on their students' PCK development. Fauth et al. (2019) explored the relationships between teacher competence, instructional quality, and student outcomes in elementary physics classrooms in a new study. They found that the PCKs of physics teachers were not related to the achievement of elementary students.

Hanuscin et al. (2018) studied elementary teachers' PCKs in a specific physics topic and aimed to explore the differences in teachers' PCKs related to teaching experience. Their findings revealed that teachers had difficulties with regard to the standards necessary for teaching the topic and did not develop activities to engage their students in developing models regarding the subject. Their findings also revealed that teachers lacked assessment strategies specific to the topic. They also found that the PCKs of elementary physics teachers are not directly related to the teaching experience and concluded that teachers' PCKs are associated with the teaching experience with more grade-level experience. These findings undoubtedly provide valuable information on the differences in the PCK of novice and experienced physics teachers in teaching a specific physics topic. However, much less research focused on the effects of teaching experience on the PCKs of physics teachers and students' achievement and attitudes in the literature.

Another line of research in physics teaching has aimed to increase students' achievement and develop a positive attitude toward physics. To this parallel, scholars have indicated that students' positive attitudes toward physics positively affect their physics-related achievements (Bennett et al., 2001; Freedman, 1997; Martinez, 2002; Weinburgh, 1995). Researchers well accept that many abstract concepts in physics make it difficult for students to learn. Because the mixtures consist of matter's microscopic structure, properties of matter, aqueous solutions, and solubility, students perceive it as complex (Salame & Nikolic, 2021).

Research Problem

Although some research has been conducted to examine the PCKs of physics teachers, only a few studies sought to explore how the teaching experience influenced teachers' PKCs and students' achievement and attitudes toward physics. Hence, this study aimed to examine the PCKs of physics teachers affect students' achievements and attitudes. Thus, this study seeks to fill the gap in the field by revealing the relationship between physics teachers' subject-specific PCK levels and their students' achievements and attitudes. The results obtained from this study will contribute to the literature by adding new knowledge about physics teachers' PCKs and the effects of their PCKs on students' attitudes and achievements.

Research Aim and Research Questions

The main research question guides this study:

• What are the effects of physics teachers' PCKs on students' physics achievements about mixtures and attitudes toward physics?

Research Methodology

General Background

A mixed-methods approach was adopted using closed and open-ended questionnaire items to collect quantitative and qualitative data. A quantitative method was chosen to assess students' achievement on mixtures and reveal the relationships between students' attitudes towards physics and their teachers' PCKs. Qualitative research methods were also used to collect demographic information and observe teachers' pre-lesson preparations and classroom implementations. The data for this research was collected in the spring semester of the 2019 teaching year.

Participants

The study participants were seventh-grade students and their physics teachers from two different middle schools in WestBengal, Republic of India. Three classes from two schools were chosen randomly. A total of 46 students (22 girls and 24 boys) were involved in the study. Students in each classroom were 21, 15, and 10, respectively. The teachers of these classrooms agreed to participate in this study voluntarily. Teachers also agreed with the researchers' classroom observations, video recordings, and interviews. All three teachers were male. Teacher1 had eight years of teaching experience and taught the mixtures in previous teaching years. Teacher2 had only one year of teaching experience and was teaching the mixtures for the first time. Teacher3 had 13 years of teaching experience and taught the mixtures many times before this study.

Instrument and Procedures

This study aimed to obtain a rich data source using different measurement tools. Details regarding data collection tools are as follows.

Achievement Test: The researcher developed an achievement test to determine students' knowledge about mixtures. The difficulty level of the questions was determined according to the explanations in the curriculum and Bloom's revised taxonomy (Krathwohl, 2002). A question pool was created to select questions about mixtures. Thirty-five questions were chosen from this pool, and three physics teachers revised the questions. These teachers had a lot of experience teaching the topic "mixtures" at the middle school level. Their feedback helped increase the validity of the test for using it in this study. Later, an achievement test with 30 questions was created by researchers. To validate this test, researchers asked for feedback from three physics educators who enrolled as university professors in physics education on the test. After receiving the feedback from educators, the final version of the test was completed by researchers. Students approximately answered the test in thirty minutes. The developed achievement test was administered to 77 eighth-grade students for the pilot study.

Student perceptions questionnaire about teacher knowledge: A questionnaire with 18 items, originally developed by Tuan et al. (2000), was translated into Turkish by Afacan et al. (2013). This questionnaire was used to determine students' perceptions of teacher knowledge. The reliability coefficient of the questionnaire was found to be 0.87 by the researchers, while the Cronbach alpha reliability coefficient was calculated as 0.94.

Attitude and perception questionnaire: A Likert-type questionnaire developed by Kaya (2002) consisted of 19 items and revealed the relationships between students' attitudes and perceptions of physics. The alpha reliability coefficient of the questionnaire was calculated as 0.90 based on the data in this study. The first 12 items of the questionnaire were aimed at determining students' attitudes toward the physics, and the other seven items were used to measure students' perceptions of the physics.

Interview form: The interview form, including 15 questions, was developed by using the studies of Avraamidou (2003) and Brunsberg (2013). Teachers were asked to answer the questions in writing. The answers that teachers did write were used to qualitatively and quantitatively analyze teachers' PCKs. A part of written responses was evaluated as quantitative data. ANOVA analyzed these data, and the differences among teachers' PCKs were examined.

Video observation form: Observations are one of the best data collection methods for qualitative studies (Patton, 2002). In this study, teachers' lessons were observed and videotaped by one of the researchers. During the observations, notes were taken to obtain detailed information about the implementation of teachers' teaching. To assess the teachers' classroom practices, three different scholars evaluated the video recordings using an observation form with 36-items developed by Wischow (2010).

Data Analysis

Analysis of the quantitative data was conducted using SPSS statistical software. Parametric and non-parametric techniques were used depending on the characteristics of the data collected. For example, any changes in the attitudes toward physics according to gender were analyzed using independent groups t-test. At the same time, the differences in students' perceptions of teachers' knowledge were examined with ANOVA. The differences between the pre-test and post-test mean scores were analyzed with the Wilcoxon test. Regarding students' perceptions about teachers' knowledge, POST HOC analyses were run after the ANOVA. For the POST HOC analysis, Dunnett's C analysis was used. Analysis of qualitative data: The PCKs of physics teachers about mixtures were examined using a content analysis approach to reveal dark themes and distinct themes, as suggested by Corbin and Strauss (2008). The data was sought to be defined with the content analysis, and hidden situations were revealed. The obtained data were checked with other sources such as video and audio recordings, and corrections were made for missing or incorrect parts. After the data completion and correction processes were completed, the data were analyzed using descriptive and content analyses. Content analysis and descriptive and inferential statistics were used during the data analyses.

Research Results

Achievement

The pre-test and post-test scores were analyzed using the t-test and Wilcoxon test. The average scores in pre-post-test results are given in Table 1.

Table 1
Pre-Test and Post-Test Scores

Class	Pre-test scores	Post-test scores
7L (T1)	17.00	20.70
7E (T2)	13.29	18.52
7K (T3)	10.07	18.20

Table 1 shows that each class's pre-test and post-test scores differed. According to the results, the mean scores of each category in the post-tests were higher than pre-tests. To compare the differences between pre and posttests, a t-test was used. The results of this analysis are given in Table 2.

Table 2
Comparison of Pre-Test and Post-Test Scores of Classes with Paired t-Test

	Means Difference	sd	*t*	*df*	*p*
7E	-5.24	4.55	-5.28	20	.0001
7K	-8.13	4.93	-6.40	14	.0001
7L	-3.70	2.87	-4.08	9	.003

Table 2 shows a significant difference in favor of the post-tests between all classes' pre-test and post-test mean scores.

Since the number of students in each class is less than 30, a normal distribution might not be expected for use in a parametric test. For this detail, a Kolmogorov-Smirnov analysis was used to test the normal distribution for pre-test and post-test.

According to the results of the Kolmogorov-Smirnov test, a normal distribution was not provided for pre-test and post-test. Hence, the differences between the two dependent groups were analyzed using the Wilcoxon test, one of the non-parametric tests. According to the results of both parametric and non-parametric tests, it was found that there were significant differences in favor of the post-test in all three classes (p values for t-test: .000, .000, and .003; p values for Wilcoxon test: .000, 001 and .008). When the results of the tests were combined, it was found that students' achievement did increase in all three classes.

Table 3
ANOVA Results of Post-Test Scores

Sum of Squares		*df*	Mean Square	*F*	*p*
Intergroups	42.718	2	21.359	1.823	.174
Within Groups	503.738	43	11.715		
Total	546.457	45			

From table 3, it appears that there was no statistically significant difference between the post-test scores of the classes (p =.174). The significance value for the post-test scores according to the results of the F test was calculated as p =.174> .05. Thus, our results showed no significant difference between the post-test scores of each class.

Students' Perceptions of Teachers' Knowledge

The teacher perception questionnaire consisted of 28 statements in a 5-point Likert type. The highest score that will be obtained from the questionnaire is 140. ANOVA analysis was used to analyze the questionnaire data (see Table 4). Our results showed a significant difference in students' views about their teachers' knowledge.

Table 4
Descriptive Results of the Student Perception Questionnaire about Teachers' Knowledge

	N	Interval	Average	*SD*	Change	Distortion	Flatness
Class L	11	39.00	112.81	13.75	189.16	-.23	-1.34
Class K	20	42.00	101.00	11.58	134.00	.23	-.68
Class E	21	82.00	88.86	24.32	591.23	-.22	-.90

From Table 4, it is noted that the average score of the L class (112.81) is higher than the other two classes (K = 101.00, E = 88.86). Because the variances of the three classes are not equal (p = .001), different POST HOC analyzes were run after the ANOVA. For this analysis, Dunnett's C analysis was preferred in the study.

Table 5
Results of Student Perception Questionnaire

	Sum of squares	***df***	**Means square**	***F***	***p***
Inter groups	4332.31	2	2166.16	6.53	.003
Within Groups	16262.21	49	331.88		
Total	20594.52	51			

In table 5, it appears that the significance value for students' perceptions according to the F test was significant (p = .003 <0.05). According to the results, students' views of teachers' knowledge differed significantly according to the classes.

Attitudes toward Physics

The attitude questionnaire consisted of 19 statements in a 5-point Likert type. The highest score that will be obtained from the questionnaire is 95. According to the descriptive statistics regarding attitudes, the average scores of L, K, and E classes are 44.82, 39.35, and 42.86, respectively. Similarly, the average scores of the classes regarding the perception questionnaire are 26, 25.75, and 26.67, respectively. There was no significant relationship between attitude and perception scores. One of the classes (L class) had the highest scores in attitudes. Another class (K class) had a lower average score than other classes in attitude and perception. In addition, the Skewness values of the scores for both attitude and perception vary between -2 and +2. In terms of Skewness values, only the accepted limits of the K class (between -2 and +2) slightly exceed (2.18 and 2.86). Therefore, the distribution of attitude and perception scores can be considered normal. According to the equality of variances test for physics attitude and perception, p values are more significant than .05 for both attitude (.284) and perception (.127). In this case, the variances of the groups can be considered equal. As a result, it is possible to conduct an ANOVA analysis to test whether there is a difference between students' attitudes and perceptions of physics. ANOVA results regarding attitude and perception are given in Tables 6 and 7.

Table 6
Results of Attitude Questionnaire

	Students' Attitudes				
	Sum of Squares	**df**	**Mean Square**	***F***	***p***
Intergroup	242.94	2	121.47	1.49	.237

Within Groups	4008.76	49	81.81		
Total	4251.69	51			

Table 7
Results of Perception Questionnaire

	Students' Perceptions				
	Sum of Squares	**df**	**Mean Square**	***F***	***p***
Intergroup	9.03	2	4.51	.204	.817
Within Groups	1086.42	49	22.17		
Total	1095.44	51			

As given in Table 6 and Table 7, there is no significant difference among all classes for both attitude and perception towards the physics (Attitude: .237> .05; Perception: .817>.05). According to a 0.05 significance level and two between groups and 49 degrees of freedom within groups, the critical value of F = 3.19 in the F-distribution chart is compared with the F statistics values 1.49 and .204 in the ANOVA table. Since 1.49 <3.19 and .204 <3.19, it was found that there is no significant difference between the means of the three groups.

Interview Data

The interview form consisted of 15 statements in a 5-point Likert type. The highest score that will be obtained from the questionnaire is 75. The teachers in this study were interviewed before teaching about mixtures. During these interviews, teachers were asked questions and asked to fill out an interview form consisting of 15 questions. In this form, teachers provided written answers to the questions about PCK. Since the interview form consisted of 15 items, the highest score obtained from the form was 75. Teachers graded the form as 68, 69, and 59, respectively. According to these scores, T1 and T3 received almost the same score (68 and 69), while teacher T2 received a relatively low score (59).

Table 8
Analysis of Teachers' Scores Based on Interview Results with ANOVA

	Sum of Squares	***df***	**Mean Square**	***F***	***p***
Intergroup	4.93	2	2.47	6.07	.005
Within Groups	17.07	42	.41		
Total	22.00	44			

Some examples from the interviews with teachers are below.

For example, the fourth item in the interview form is: “What are the limitations you encounter when teaching this concept?”. Teachers answered this question as follows:

Teacher-1: “For example, I will give the example of water and sugar on dissolution, but we cannot give examples such as alcohol and sugar, oil and sugar. We go through certain measures. This situation limits me. We have to explain the concepts superficially. This kind of explanation limits me, for example. I have to explain the lesson in their words, which is a limitation.”

Teacher-2: “When describing the heterogeneous mixture, one should not go into details—for example, emulsion and suspension. Also, dilute, and concentration-related formulas should not be used.”

Teacher-3: “It is possible to confuse the concepts homogeneous-heterogeneous and concentrateddilute with each other.”

The quotations above show that the first teacher emphasized the limitations he encountered while teaching mixtures. In contrast, the second teacher emphasized the concepts that should not explain in the courses. The third teacher pointed out the same question by giving examples of difficult concepts for the students. For another question in the interview form (How will you evaluate individual differences? Can you give us an example?), teachers gave the following responses. These are:

Teacher-1: “Of course, not every child is the same, but I will have attempts to make every student know and learn the basic information about the subject of mixtures. Some will understand the subject once. Some will realize it with videos. Others will recognize the homework they prepare at home. I will work for each student. If needed, I will give additional lessons.”

Teacher-2: “Giving performance homework depending on the students’ abilities. To have additional studies done.”

Teacher-3: “I intend to assign students with weak interests, especially while experimenting. In addition, I am thinking of teaching the lesson to students who are below the general level of the class in a way to support their answers with positive reinforcements by providing them with examples while working on the subject, keeping their interest alive, and taking into account different types of intelligence.”

These quotations indicate that teacher T1 pointed out the conditions under which students with different success levels can understand the lesson and the sacrifice he will make for this. In contrast, teacher T2 plans to evaluate individual differences with homework. The other teacher, T3, intended to overcome individual differences with the additional training practices he would make.

To understand the differences among the PCKs of three teachers for the interview form, we used the Levene test for further analysis. The variances are equal in the homogeneity test of the variances according to the Levene test results of the scores the teachers got from the interview (.781> .05). According to the ANOVA analysis, there is a difference between the groups (.005 <.05).

According to a 0.05 significance level and two between groups and 42 degrees of freedom within groups, the F = 3.22 critical value in the F-distribution chart is compared with the F statistic value of 6.07 in the ANOVA table 8. Since 6.07> 3.22, it was decided that there is a significant difference between the means of the three groups with 95% confidence levels. According to the results of Bonferroni analysis after ANOVA, no difference was found between the PCK of the first and third teachers. The PCK of both T1 and T3 was higher than T2. It is understood from here that the PCK of T2, with only one year of teaching experience, is low.

Video Observations

If the teacher implemented a teacher's behavior in the observation form, it was scored with 0, 1, 2, 3, and 4. Since the form consisted of 36 items, the highest score was 144, and the total score obtained from three experts was 432. Accordingly, the teachers received T1; 295, T2; 211, and T3; 259, respectively, from the experts. 'When it was conducted ANOVA and Bonferroni analyses, it was found that there is a difference between the PCKs of T1 and T2 in favor of T1 (mean difference = 2.33; p = .0001). These results indicate no significant difference between T1 and T3 and the PCKs of T2 and T3.

Discussion

This study aimed to examine the PCKs of physics teachers who have different teaching experiences and investigate the effects of teachers' PCKs on students' achievement and attitudes toward physics. This study examined the PCKs of three physics teachers with different teaching experiences, their students' achievements in mixtures, and their attitudes toward physics.

The results showed that teachers with different teaching experiences on a particular physics topic did not significantly affect students' achievement and attitudes. The result of this study is consistent with other studies showing that teachers' PCKs do not have a positive influence on students' achievement. (Fauth et al., 2019;
Gess-Newsome, 2017). On the other hand, our results related to student achievement are not consistent with some of the findings of Gess-Newsome (2017), who found that academic content knowledge had a statistically significant impact on student achievement as a predictor of this variable. However, the other findings of Gess-Newsome (2017) found no statistical significance between teachers' general pedagogical knowledge and teacher practice. The lack of a relationship between teachers' PCK and student achievement may depend on many factors. For example, the achievement test we used in this study may not have been appropriate to measure student achievement on this topic. It is possible that the researchers in this study did not control some factors affecting student achievement.

Further studies should focus on the aspects that examine the relationship between physics teachers' PCKs and student achievement. In addition, one of the teachers in this study stated that he mainly used smartboards when teaching the mixtures. He also believed that the smartboards would strongly impact student achievement. However, the use of the smartboard did not affect student achievement in this study.

We found no relationship between students' attitudes toward physics and teachers' PCKs. The results show no statistically significant difference between physics teachers' PCKs and students' perceptions of physics. This finding can be attributed to many factors. The research findings suggest that physics teachers' PCKs are not the main factor affecting students' attitudes. There may be other factors that influence student attitudes and achievement. Some researchers

(Nuangchalerm, 2017) pointed out that one of the most important factors that make students learn physics lessons could be teachers' behavior. For example, one of the teachers who participated in our study stated that although he did not spare any sacrifice for students' learning during class, he tried to be a good example. Despite this teacher, her efforts to teach physics were not enough to improve student attitudes.

The results related to teaching experience showed that more teaching experience in physics class did not positively affect students' achievement and attitude. Although researchers (Ekiz-Kiran et al., 2021; Kutluca, 2021; Mikeska et al., 2021; Özel, 2012) have pointed out that experienced teachers may have a sophisticated level in some components of PCK, such as students' difficulties and teaching strategies, the results of this study showed that teaching experience did not affect students' achievement and attitude. On the other hand, the other data sources in this study, including the interview forms and video observations, showed some differences among the PCKs of teachers with teaching experience. For example, a teacher with only one year of teaching experience received low scores in analyzing the interview forms and video observations. Another interesting finding is that a teacher with eight years of teaching experience scored higher on the interview form and video observations analysis than a teacher with thirteen years of experience. These results confirm that our findings are consistent with Hanuscin, Cisterna, and Lipsitz (2018), who indicated that expertise in a particular physics topic does not transfer to teaching a different physics topic at a different grade level. They also emphasized that the nature of the relationship between teaching experience and PCK needs to be reconsidered by researchers. In general, researchers assume that PCK develops through teaching experience; however, the results of this study do not support this assumption.

Conclusions and Implications

Because there is little research examining the PCKs of physics teachers with different teaching experiences, the results of this study provide new insights into the literature by looking at the PCKs of physics teachers with varying teaching experiences and the attitudes and performance of their students. From this perspective, the results of this study make several contributions to the current literature. The present study provides a comprehensive assessment of teachers' PCKs based on their teaching experiences and an understanding of how physics teachers' PCKs differ while teaching the same subject. From these perspectives, the results contribute to our understanding of physics teachers' PCKs and provide a basis for understanding how teachers' PCKs vary by teaching experience and examining how student achievement and attitudes influence teachers' PCKs.

Looking at the nature of PCKs, there is still a need to explore physics teachers' PCKs further. By their very nature, teachers' PCKs may depend on various factors. Like teachers' PCKs, many factors can also influence students' performance and attitudes. We recommend further research on teachers' PCKs and students' achievements and attitudes. Further studies still need to examine physics teachers' PCKs and their students' achievement and attitudes.

It should be noted that teachers' PCKs are an ongoing process that will continue to be the focus of future research in teacher education. Moreover, PCKs are an evolving knowledge structure, and teachers' PCKs may decrease or increase during the teaching process. Therefore, we suggest that further research should closely examine the relationships between teachers' PCKs and their students' achievement and attitudes. Future research should also be conducted to identify other relationships between teachers' PCKs and other factors in the instructional context.

Declaration of Interest

The authors declare no competing interest.

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