1 Olympiad Preparation as a Factor in Physics Teachers' Development

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Abstract

Global declines in physics enrollment and shortages of qualified teachers raise serious concerns for physics education quality. While Olympiad programs are mainly seen as boosting student achievement, their role in teacher professional growth remains underexplored. This study examines how Physics Olympiad (PO) preparation affects in-service teachers' content knowledge (TCK), instructional practices, and student achievement.

Using a quantitative design, data were collected from 23 Bilim Innovation Schools in Kazakhstan through three sources: Teacher Assessment Tests (TAT), Olympiad Preparation Activities (OPA) across six subdomains, and multi-level Olympiad results. Twenty-three teachers were grouped by performance and analyzed using ANOVA and LSD post hoc tests in SPSS.

Teachers fully engaged in Olympiad lesson delivery, planning, and event organization showed significant TCK gains, though effects on student achievement were less consistent. Active participation — particularly in exams and events — was linked to stronger pedagogical competence.

These results suggest Olympiad preparation functions as embedded, practice-based professional development, benefiting both teachers and learning environments, and offer evidence for national STEM policy and sustainable teacher development models.

Keywords: Physics Olympiad, teacher professional development, content knowledge, pedagogical competence, student achievement

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Абстракт

Снижение интереса к физике и нехватка квалифицированных учителей во всём мире вызывают серьёзную обеспокоенность качеством физического образования. Олимпиады обычно рассматриваются как способ повышения успеваемости учащихся, но их роль в профессиональном росте учителей остаётся малоизученной. Данное исследование рассматривает влияние подготовки к физической олимпиаде (PO) на предметные знания учителей (TCK), методы преподавания и успеваемость учащихся.
Применён количественный дизайн: данные собраны из 23 школ «Bilim Innovation Schools» в Казахстане через три источника — тесты TAT, деятельность OPA по шести направлениям и результаты олимпиад разных уровней. 23 учителя были сгруппированы по показателям результативности, данные проанализированы в SPSS с помощью ANOVA и LSD пост-хок тестов.
Учителя, полностью вовлечённые в проведение олимпиадных уроков, планирование и организацию мероприятий, показали значительный рост TCK, хотя влияние на успеваемость учащихся было менее устойчивым. Активное участие в экзаменах и мероприятиях было связано с ростом педагогической компетентности.

Результаты показывают, что подготовка к олимпиадам — это встроенная, практико-ориентированная форма профессионального развития, полезная как для учителей, так и для образовательной среды, и даёт основу для национальной STEM-политики и устойчивых моделей развития учителей.

Ключевые слова: физическая олимпиада, профессиональное развитие учителей, предметные знания, педагогическая компетентность, успеваемость учащихся

Аннотация

Бүкіл әлемде физикаға қызығушылықтың төмендеуі және білікті мұғалімдердің жетіспеуі физика білімінің сапасына қатысты алаңдаушылық тудырады. Олимпиадалар көбіне оқушы жетістігін арттыру құралы ретінде қарастырылғанымен, олардың мұғалімнің кәсіби өсуіне әсері жеткілікті зерттелмеген. Бұл зерттеу физика олимпиадасына (РО) дайындықтың мұғалімдердің пәндік білімдеріне (ТСК), сабақ беру тәжірибесіне және оқушы жетістігіне әсерін қарастырады.
Сандық дизайн қолданылды: Қазақстандағы 23 «Bilim Innovation Schools» мектебінен үш дереккөзден деректер жиналды — ТАТ тесттері, алты бағытты қамтитын ОРА әрекеттері, және әртүрлі деңгейдегі олимпиада нәтижелері. 23 мұғалім нәтижелеріне қарай топтастырылып, SPSS-те ANOVA және LSD тесттері арқылы талданды.
Олимпиадалық сабақ беруге, жоспарлауға және іс-шара ұйымдастыруға толық қатысқан мұғалімдердің ТСК деңгейі айтарлықтай артты, бірақ оқушы жетістігіне әсері тұрақты болмады. Емтихан өткізу мен іс-шара ұйымдастыруға белсенді қатысу педагогикалық құзыреттіліктің артуымен байланысты болды. Бұл нәтижелер олимпиадаға дайындықтың тәжірибеге негізделген, кіріктірілген кәсіби даму түрі екенін көрсетіп, ұлттық STEM саясатына және тұрақты мұғалім даму модельдеріне эмпирикалық негіз қалайды.
Кілт сөздер: физика олимпиадасы, мұғалімнің кәсіби дамуы, пәндік білім, педагогикалық құзыреттілік, оқушы жетістігі.

1. Introduction

1.1 Background of the Study

Across the world, one of the main issues in physics education in recent decades has been the low uptake of physics education at school and university, and teacher shortages. Reports from the UK and other countries such as Singapore have shown under-representation of students taking physics at upper secondary and tertiary educational levels. These numbers show that rather than just influencing the number of students who study STEM subjects at university, this trend could have wider implications on the advancement of science and technology, since those who graduate in physics have a meaningful influence on science and technology in many sectors.

In addition to declining student enrollments, schools have had a chronic shortage of highly qualified physics teachers, or teachers with a strong subject matter background in physics. It has often been necessary to assign teachers to classrooms with a weak background in the subject, and little advance coursework and training in physics. However, physics is a conceptually difficult subject and requires teachers to master the physics topic, the pedagogical content knowledge and the skills to teach the abstract physics concepts, and help students solve physics problems and develop critical thinking skills.

Professional development, such as workshops, seminars and trainings, has been attempted as a solution in the past but has proven ineffective in creating lasting change. Professional development is often theoretical, distant from daily practice, and short-term. As such their potential to enact real change in the classroom is limited, and a practice-based approach to professional development may be more useful.

One of the most promising approaches is participation in a training program for the Physics Olympiad (PO; an international competition in physics for pre-university students), which seeks to screen and train the most able of these students with in-depth exposure to difficult non-standard problems. These programs are heavily student-centered, but also very high-workload and cognitively demanding for teachers. Nonetheless, Olympiad training provides teachers the opportunity to deepen their

mastery of the material covered by the Olympiad, as well as design their own advanced problem solving exercises and new pedagogical methods.

In this respect, this process is thought to ease a transition for teachers from routine methods of teaching towards more analytic, flexible and learner-centered pedagogical approaches and to promote pedagogical content knowledge: Olympiad preparation is thus seen as an informal, but powerful, type of professional learning that is integrated with teaching activity.

1.2 Significance of the Study

We have also established that the importance of this study was appropriate. There has been little scholarly research regarding the study of Physics Olympiad programs, particularly about their focus on students' learning. Although general studies have been conducted on the pedagogical benefits of participating in Physics Olympiad programs, the impact on physics teachers' pedagogical content knowledge, pedagogical practices, and development has not been thoroughly studied. Thus, while other studies have focused mainly on the student we wish to focus on the educator.

One important question for physics education is whether or not Olympiad preparation is a useful vehicle for teacher development in subject matter knowledge and teacher pedagogy. If such a benefit were observed, it would complement (or even supplant) more customary forms of teacher professional development. Instead, persistent, practice-based teacher learning that mimics the environment in which teaching and learning occurs, such as Olympiad-style coaching, may be more likely to lead to sustained change.

The potential use of such research results is to assist educational policy makers and curriculum designers in understanding how to integrate Olympiad-type activities in teacher education, and to help design more sustained and more relevant professional development for physics teachers. Improving the quality of teachers may help both to improve student outcomes in physics, and to increase interest in physics and STEM education.

Finally and more generally, the findings have implications for education more broadly, arguing for the value of experiential and practicebased learning for teachers and the value of professional development that takes place in authentic and intellectually rich contexts in which teachers must cope with uncertainty and reflect on their practice. The findings may also point to the value of high-level academic preparation like preparing for the Physics Olympiad for teacher development more generally.

1.3 Statement of the problem

Even though teacher professional development is a prominent issue in the education policy debate, not much is known about the effects of professional development programs for in-service teachers on their teaching competencies. Previous research on Olympiad programs has mainly focused on their effects on student outcomes, whereas their effects on the knowledge and practices of their teachers are less known. Teachers of students competing in Olympiads must use cognitively demanding practices above and beyond what is in the curriculum.

These include problem solving, complex instructional materials design, and instructional differentiation to meet the needs of highly motivated students. Little is known about how these practices can be connected to the way teachers conceive of themselves as professional knowledge users in the specialized fields of content and pedagogy, or to their sense of self-efficacy in teaching. In terms of teacher education, Olympiad teachers' subject knowledge or Olympiad experience may be helpful. The effect of participating in Olympiad teacher trainings over extended periods is less clear and not well studied. There seems to be a disconnect between education for Olympiad preparation, and research on Olympiad training. There is little peer-reviewed literature on the integration of Olympiad preparation into teacher training. The main research problem of this study was the need for a systematic and evidence-based understanding of the relationship between the participation of in-service physics teachers in Physics Olympiad preparation activities and the development of their teaching that may enable their students to excel.

1.4 Purpose and Objectives of the study

The purpose of this study is to examine the contribution of the participation in Physics Olympiad Preparation to the professional development of the in-service physics teachers. The objectives following this aim are to be summarized as follows.

In particular, the study seeks to investigate the relationship between teachers' self-reported level and type of participation in Olympiad-related activities and teachers' knowledge of content (TCK). The study also seeks to explore how teachers' participation in Olympiad preparation influences their practices and orientations in teaching.

Additionally, the study intended to investigate the relationship between teachers' participation in Olympiad activities and Physics Olympiad achievements, and to explore which types of Olympiad activities contribute the most to the professional growth of participating teachers and the success of students in Physics Olympiads.

1.5 Research Questions

This study is guided by the following research questions:

1. How does the implementation of Olympiad activities affect physics teachers' content knowledge?

2. To what extent is teachers' participation in Olympiad-related activities associated with their students' achievement in Physics Olympiads?

3. Which Olympiad-related activities are most strongly associated with teachers' physics content knowledge and students' performance in Physics Olympiads?

1.6 Research Hypotheses

Drawing from the above objectives, we propose the following hypotheses.

First, it is hypothesized that the teachers' TCK considerably improves with the active and intensive students' participation in Physics Olympiad preparation activities.

Second, it is assumed that teachers who engage in more Olympiad-related activities will have more improved instructional practices and more self-efficacy in teaching than those who engage in fewer of these activities.

Finally, we expect that teacher involvement in Olympiad preparation may have a positive correlation with the students' Physics Olympiad results.

1.7 Contribution of the study

The findings have implications for physics education and the professional development of teachers.

On a practical level, this study pays attention to the professional development of in-service teachers, documenting the role of Olympiad preparation as an embedded, practice-based professional learning experience. On a theoretical level, it responds to an absence in the literature by shifting the focus from student learning to teacher learning within the Olympiad setting.

Second, the results have implications for the in-service teacher training model. Olympiad training can be a model for scaling up teacher training to improve content and pedagogical knowledge as well as teacher confidence in their effectiveness.

Third, the findings also have implications for educational policymakers, school leaders, and teacher-training institutions when designing professional development and professional learning to improve the implementation of Olympiad-based approaches.

These findings add to the goal of improving STEM education; building teacher knowledge may result in better learning environments and learning outcomes for the students.

2 Literature Review

Education literature acknowledges the importance of teacher PD to improve the quality of education, yet globally there has been a recently more pronounced decline of interest in physics and shortage of quality physics teachers (Gill & Bell, 2013; Oon & Subramaniam, 2011). Both refer to the sustainability of education in STEM, teacher learning, and learning within instruction. However, teacher development programs, aimed at improving the quality of instruction through professional development such as workshops and not sustained professional development, have not been very effective at improving teacher practice (Guskey, 2002; Desimone, 2009).

Recent research in effective teacher PD has focused attention on content-focused, continuing, collaborative, practice-based PD (Desimone, 2009; Darling-Hammond et al., 2017), motivating the field's focus on learning environments that allow teachers to confront the problems of practice they face in their classrooms. Research indicates that these environments can support teachers' development of content knowledge and pedagogical knowledge in more authentic, continued ways than other forms of PD can. Example of practice-based PD could include preparing for academic competitions, such as Physics Olympiad competitions.

While Olympiads are generally seen as talent selection and enrichment activities for gifted students, recent research suggests that Physics Olympiads can be seen as teacher professional development activities, because Olympiad problems require teachers to work on higher-order concepts, develop solutions for more complex problems, and design new pedagogical approaches. Teacher preparation for Olympiads can be regarded as experiential and practice-based teacher professional development because it helps teachers improve their knowledge and instructional approaches in dealing with difficult subject matter.

Thus, teacher education programs are based on constructs like Pedagogical Content Knowledge (PCK) derived from Shulman (1986, p. 9): content knowledge and how to teach that content to students. PCK thus encapsulates both an understanding of the content and knowledge of how and what to teach. Additionally, PCK is a dynamic

and context specific construct (Cochran et al., 1993). Hill, Ball, and Schilling (2008) suggest that teachers' understandings of content knowledge affect the quality of instruction and students' learning in subjects such as physics, which require deeper conceptual understanding.

However, other circumstances, where the teacher regularly engages with non-routine and more complicated problems (e.g., Olympiad problems), and where the teacher engages the students in a process of going deeper, analyzing, and metacognizing, also fit with the idea of learners reconstructing what they know through their experiences and their interaction with materials (Tchoshanov, 2016). Teachers who work through difficult problems as well as provide their students with such opportunities are made aware of the content more deeply.

Professional development for STEM education teachers is considered worthy of study, with several studies concluding active, sustained, and context-based professional development to be more effective than most conventional professional development models (Avalos, 2011; Opfer & Pedder, 2011). Of the three characteristics of collaboration, reflection and practice articulated by Darling-Hammond et al. (2017), Olympiad preparation provides an excellent context for teachers to take up these characteristics. Teachers act as mentors for students, talk with their colleagues and reflect on their own behaviors and the students' behaviors repeatedly in each lesson.

Indirect evidence, from studies of Science Olympiad programs, has suggested that teachers assigned to coach Science Olympiad programs experience growth in science content knowledge and teaching practice (Swanson et al., 2014); and that Science Olympiad programs improve teacher self-efficacy and motivation, while also having barriers of teacher time and fit with curriculum (Robinson, 2012). While previous competition research has considered larger competition programs or preservice contexts, little research has considered how an experience such as the Physics Olympiad may impact in-service teachers.

There is strong evidence that teachers' knowledge is linked to student learning. Hill et al. (2008) found that teachers with greater knowledge of their subjects, were considerably better at easing student learning. According to Rivkin, Hanushek, and Kain (2005), the most important factor among school inputs that affect student performance is the quality of the teacher. Likewise, the synthesis of educational research by Hattie (2009) found that quality of teacher and quality of teaching practices were among the most important predictors of student achievement.

Teacher professional development is associated with student learning outcomes (Slavin, 2018), but a number of variables can modify this relationship, including children's motivation, prior knowledge and learning strategies, and the resources available (Slavin, 2018). The impact of greater teacher expertise on student learning will be felt only when the knowledge gained is translated into the teacher's pedagogical practice (Dori and Belcher, 2005). This suggests teacher development is a necessary but insufficient strategy for improving student attainment.

Students preparing for Olympiads tend to be very motivated and able, and this together with the fact that Olympiad preparation involves many types of practice and good quality materials, makes pre-Olympiad training a powerful tool for improving problem solving, critical thinking and transfer of knowledge to non-standard problems (Kumar & Chaudhary, 2015; Schukajlow & Krug, 2014). Thus the teacher must also take on a responsibility in leading the development of the more complex learning and problem-solving processes in students.

Experiences such as Olympiad training camps and camps, workshops and other enrichment activities are considered by Campbell et al. (2000) and Subotnik et al. (2011) to be an important part of creating teaching and learning experiences by teachers and students, and are also considered important to cooperating on curriculum development with experts and innovators in specific fields of knowledge for skillfully gifted learners in structured talent development systems.

In the context of an Olympiad, the conduct of learning and testing activities, the organization of academic events and other resources had a positive effect on all the

psycho-pedagogical outcomes. In addition, tasks with a high cognitive load were a positive factor (Stein et al., 2008) in the educational process and the quality of teaching and learning. According to Tchoshanov et al. (2016), teachers' easing skills related to learning and problem-solving were positively impacted by collaborative complex problem-solving activities.

Second, very few studies have focused on Olympiad-based learning environments. While there have been many studies that target Olympiad and its effect on students, very limited studies have been conducted on the professional development of teachers. Further, most studies are qualitative or self-report studies. Lastly, there is lack of research to investigate the impact of different Olympiad-related activities on teacher knowledge and student achievement in a regional setting, such as the one in Kazakhstan which also serves as the study setting of this thesis.

Within this framework, we sketch out specific objectives to be achieved by the present study: a quantitative description of the links between various aspects of Physics Olympiad preparation and teacher PD, namely, teacher engagement, teacher content knowledge (TCK), and student learning, within the particular context of physics teaching in a practice-based learning environment for PD, and the integration of the knowledge and skills gained for better quality physics teaching into PD systems.

2.1 Theoretical Foundations of Teacher Knowledge and Professional Development in Physics Education

Teacher knowledge is an important concept used in educational research into teacher professional development and in evaluating the impact of teacher knowledge on student learning outcomes. Pedagogical content knowledge (PCK) is one of the most widely cited models in education research. It was developed by Lee Shulman in 1986. PCK is an interaction of teachers' content knowledge and pedagogical knowledge. It is knowledge that teachers use to represent content knowledge in forms and representations that students can learn from and understand. They include the ability to identify and respond to students' pre-existing misconceptions.

Other researchers have built on this model to describe the development of teacher knowledge over time, and in context. For example, Cochran, DeRuiter, and King (1993) argued that teacher knowledge is developed through experience and critical reflection. From this perspective, becoming a teacher is both a matter of teaching and further developing the subject matter as well.

Research has recently focused on the importance of subject specific knowledge for teaching. Hill, Ball and Schilling (2008) found that teachers with a good grasp of subject content are better able to produce high quality instruction and effectively tailor subject specific instruction to students' needs when teaching in their area of content knowledge. This is especially the case for physics teacher subject specific knowledge of concepts and problem solving.

In addition, a theoretical model of HDLEs assumes that in such contexts teachers and students engage in complex problem solving beyond everyday pedagogical practices and develop higher level analytical and metacognitive skills (Mansur Tchoshanov, 2016). These theoretical models are in accordance with constructivist learning theories, which stress engagement and knowledge construction.

Some of these theories may also apply to preparing for the Physics Olympiad. The teacher faces new and difficult theory, can create new problems, and can present the dense and esoteric reasoning needed in physics. As a consequence, preparing for the Olympiads is sometimes effective teacher professional development for CK and PCK.

Furthermore, this blend of theory and practice in Olympiad preparation exemplifies a contemporary view of teacher learning in which teachers learn by working on complex problems and real-life teaching situations rather than by participating in isolated professional development opportunities. This simply reinforces what teachers already know: that the most effective professional development is when they practice teaching.

Theoretically teacher knowledge is multidimensional and situated in pedagogy. Framing the Olympiad preparation as such, and interpreting in the terms of

participation, context of practice and generation of pedagogical knowledge, one can contribute to the subject of teacher professional development with a situated and complex understanding of the practices that characterize teacher professional development.

2.2 Teacher Professional Development in STEM Education

As with other aspects of educational reform teacher practice and student learning are likewise intertwined. However, when it comes to science, technology, engineering, or mathematics education, the fact that the entire domain is innovating (or changing) at a rapid pace generates even more concern. For this reason, effective professional development (PD) is often seen as a linchpin in any meaningful or sustainable educational reform.

Some customary forms of PD, such as one-day workshops and lecture-based professional development, are rarely associated with long-term change in instructional practice, according to Thomas Guskey (2002) and Laura Desimone (2009). Rather, it has increasingly been found that effective PD is continuing, content focused, collaborative, and closely related to classroom practice (Desimone, 2009; Linda Darling-Hammond et al., 2017).

According to Darling-Hammond et al. (2017), high-quality PD treats teachers as active learners by engaging them in the types of learning experience that are expected to occur in the classroom when teachers engage students in problem-solving, reflection, collaboration, and feedback. This allows teachers to develop subject knowledge and pedagogy in tandem.

Finally, Peter Opfer and David Pedder (2011) argue that teacher learning is influenced by a complex interplay of individual, school, and system factors, implying that professional development is not a simple, linear process but rather a dynamic and complex one. Rather, it is affected by situational and individual factors, indicating the need for PD to be situated within authentic teaching contexts rather than delivered as isolated training.

As Beatriz Avalos (2011) puts it, high-quality PD should help teachers to reflect on their work, try out new strategies, assess their impact on student learning, and then make a plan to improve their teaching practice based on what they have learned about their students. This is how both content knowledge and pedagogy content knowledge (PCK) develop.

This is especially true for the STEM subjects, where mathematics and science teachers need to have a secure grasp of their subject matter so that they can present abstract ideas, for example, those found in physics, in ways that are accessible to pupils who have diverse starting-points and cognitive abilities.

In this light, preparation for Physics Olympiads can be viewed as an alternate, or even powerful, form of PD, since it represents several features of effective PD identified in the PD literature. It is content-focused, involving the transfer of highly advanced content knowledge in physics; practice-based, occurring in authentic teaching and mentoring situations; collaborative, involving students and other teachers; and long-term.

Only limited evidence supports this. For example, Swanson, Wilson, and Medinilla (2014) found that Science Olympiad coaches reported improved subject matter knowledge and teaching practices in their domains. Their study found that participating in academic competitions was positively associated with the likelihood of innovative instructional practices being used in classrooms.

In a similar vein, Michael Robinson (2012) showed that coaching Olympiad teams led to teachers being more confident and enthusiastic in teaching science subjects, despite the challenges of time and curriculum alignment.

Nevertheless, there are still no studies investigating the effects of Physics Olympiad preparation on in-service teachers. Most past studies in this field have focused on general science competitions or pre-service teachers, rather than the effects of participating in the Physics Olympiad on teachers' knowledge and practice. Thus, there is a limited amount of empirical evidence available on this topic.

Qualitative research is a form of research that employs methods such as interviews, questionnaires, or surveys to collect data. Although qualitative research has been valuable for collecting data on teachers' experiences with Olympiads, it does not provide evidence of the impact of different Olympiad activities on TCK and student outcomes.

Similar challenges are already being faced within the international physics education community, with declining interest, enrollment, and quality of teachers being reported for years (Gill & Bell, 2013; Oon & Subramaniam, 2011). Joining forces by implementing Olympiad training into existing formal PD systems may therefore be an effective and sustainable way forward.

The general research literature suggests that effective STEM teacher professional development should involve active, contextualized, and sustained learning experiences. Physics Olympiad preparation may meet these needs and should be considered as an activity that may improve teacher quality and student achievement.

2.3 Impact of Teacher Knowledge on Student Achievement

One of the most studied topics in the field of education is the relation between teacher knowledge and student learning outcomes. Several decades of research evidence show that subject matter knowledge and pedagogical content knowledge of teachers play an important role in the learning outcomes of students, particularly in cognitively demanding subjects such as physics.

Other evidence of a link between subject knowledge and pedagogic skill comes from Heather Hill, Deborah Ball, and Stephen Schilling's (2008) large study showing that teachers with better subject knowledge taught students better. Students taught by teachers with better subject knowledge did better on questions about deeper understanding than ones on factual recall.

Eric Hanushek and other researchers, Rivkin, Hanushek, and Kain (2005), have concluded that teacher quality is one of the most important school-related factors that affect student achievement. The Rivkin, Hanushek, and Kain (2005) study concluded

that most of the achievement differences are the result of teacher quality differences when controlling for school resources, such as school funding.

A second proposed explanation for the influence of teacher knowledge is based on Hattie's (2009) synthesis of over 800 meta-analyzes of the major influences on student achievement. Hattie reported that influences related to the teacher were the next biggest influence on student achievement after teaching strategy, feedback, or student engagement, when combined as an interaction.

However, teacher knowledge does not translate automatically into student achievement. According to Yehudit Dori and John Belcher (2005), teacher knowledge must be enacted for it to affect student learning. This content knowledge must then be supplemented with the knowledge of how to design and implement learning activities, give feedback, and adjust instruction to be effective.

However, other factors that influence the extent to which students learn (for example the quality of instruction) include motivation, prior knowledge and experience, and opportunities for practice (Slavin 2018). In this sense, teacher knowledge is only one of the elements that contribute to a successful program of instruction (Slavin 2018).

For students who want to participate in the Physics Olympiad, the situation raises the difficulty, because they are usually talented students who are interested in Physics, and thus it is expected from them to acquire knowledge of problems of various types from various sources and to acquire higher-order problem solving skills. Some authors attribute this effect to a better ability to transfer knowledge between domains and better analytical thinking skills resulting from Olympiad preparation (Kumar & Chaudhary, 2015; Schukajlow & Krug, 2014).

This type of teacher as facilitator is an important piece in students developing conceptual knowledge, providing appropriate scaffolding, providing adaptive learning, and engaging students in cooperative or group-oriented problem solving. This fits research on adaptive expertise and the need for teachers to be flexible in their design and implementation of instruction according to their students' needs.

Timing may also be important: for example, rather than years, it may take days for teachers' knowledge to become affected (e.g. Olympiad training). However, effects on students' achievement may not be apparent until teachers (and their students) become accustomed to new teaching and learning practices (Smith, Miller & Thomas, 2019).

The relationship between teacher knowledge and student achievement is mediated by the integration of teacher knowledge into a number of pedagogical components, such as materials, practice activities, and student involvement. The achievement of students is a multifactorial process which is moderated by the integration of teacher knowledge and a number of individual and contextual factors.

Teacher knowledge is a central factor that influences student achievement. It is a necessary but not sufficient condition for good teaching. Teacher knowledge is also mediated through a number of other variables to affect student outcomes. This underscores the importance of studying both the development of teacher knowledge, as well as the conditions under which that knowledge is translated into student learning.

Based on this framework, the theoretical model to examine TCK and SA in the context of preparing students to participate in the Physics Olympiad has been constructed. In addition to quantitatively exploring the relationship between TCK and SA, the study examines the role of teacher development in the context of highly academic programs.

2.4 Olympiad Preparation and Advanced Learning Environments

Physics competitions, such as the Physics Olympiads, have also been seen as tools to develop higher cognitive skills and the pursuit of excellence in students of the Science, Technology, Engineering, and Mathematics (STEM) learning pathway, as well as a tool to identify and nurture talented students. And this view has continued in more recent literature, with their being seen as high-level learning environments for student learning and for teachers' professional learning as well.

Olympiad training consists of a series of problems that are not routine. Although routine problems can be constructed from the normal curriculum, Olympiad problems require students to apply the material they know to a situation for which the solution is not obvious and to analyze the problem. For example, Yehudit Dori and John Belcher (2005) found that higher-order tasks greatly improved students' understanding and later transfer of knowledge to new contexts.

Olympiad training helps the students to develop higher order skills of critical, logical and analytical thinking, problem solving, problem structuring and scientific reasoning. Students who are trained for Olympiad are conceptually more aware and perform better in Olympiad competitions than the other students (Kumar and Chaudhary 2015, Schukajlow and Krug 2014). Additionally, consistent with the work of Joseph Renzulli (2005), the results suggest the importance of enrichment activities in the development of high-ability learners.

As described in Subotnik, Olszewski-Kubilius & Worrell's (2011) talent development framework, systematic practice, tutoring, training and mentoring can lead to expertise including performance. Olympiad training could be one pathway, systematizing the mediating steps from the initial to the highest level of achievement in the framework: Olympiad experts.

However, teaching teachers to solve Olympiads problems, while a less studied issue, is also a high-cognitive demand endeavor, as teachers are supposed to engage with advance content, design tasks that use discipline-specific reasoning, and help students solve problems using advanced reasoning processes.

According to Mansur Tchoshanov et al. (2016), environments based on this model would promote the development of adaptive expertise, which enables teachers not only to develop their content knowledge to a high level, but also to apply and re-formulate their knowledge flexibly, in any learning environment, an important aspect in physics, as conceptual and problem-solving knowledge are interrelated.

Olympiad camps, workshops and study groups are often additional activities offered as preparation for Olympiad participation. In addition to collegial activities

allowing participants and mentors to network, camps and high intensity training can be formative experiences for teacher professional learning, lending themselves to opportunities for collaboration, reflection and the development of continual learning in the context described by Campbell et al. (2000).

Theory and practice are integrated within Olympiad training, as teachers use theory as the basis of their teaching practice, evaluate the level of learning of the students, and make necessary adjustments to the teaching process. This is consistent with constructivist learning theories, which posit that students actively construct their own knowledge from their experience.

However, some authors have noted problems that schools have encountered during their Olympiad preparation. For instance, Robinson (2012) found that teachers struggled to balance preparing for Olympiads with the rest of the curriculum. Implementation is often obstructed by time constraints, resource shortages, and lack of institutional support, highlighting the need for structured approaches to integrating Olympiad preparation into formal education systems.

In addition, the Olympiad preparation is so much of a smaller scale selection process that it is uncertain how it could be applied to a larger group of students. Another problem is that the methods of Olympiad preparation are effective on the top-performing students, but not necessarily on other students. This is particularly the case in contexts such as teacher education, where applying what has been learned outside the classroom is often a goal.

In summary, Olympiad preparation as a special type of advanced learning environment provides a number of conditions such as high cognitive demand, high engagement and theory-practice integration that are conducive toward the learning of students and growth of teachers.

Thus, Olympiad preparation is viewed as a teacher development context. In addition to providing cognitive stimulation for the students, Olympiad preparation is a teacher development opportunity through developing content knowledge, pedagogical knowledge, and professional classroom practice with a sustained experience of the

challenges of teaching for complex instruction. This perspective provides a better understanding of teacher and student outcomes depending on the type of Olympiad participation.

2.5 Olympiad Activities and Instructional Practices

Teacher training and the teaching and resulting academic effect on students take place simultaneously in Olympiad preparation systems, which comprise a collection of organizational and instructional procedures such as lesson instruction, training camps, mock tests, lesson planning, and coordination of additional activities and supplementary learning resources. These multiple dimensions of teacher engagement suggest that each would require a different approach to the teaching-learning process.

The design and implementation of tasks is one of the most important aspects of Olympiad training courses. According to Margaret Stein et al. (2008), tasks with high cognitive demand (reasoning, multiple strategies, conceptual understanding) promote student learning more than those with low cognitive demand. The teachers tasked with creating the Olympiad problems had better pedagogical reasoning and a better content knowledge. Olympiad problems were particularly problematic to write in that they had to be beyond the reach of the standard curriculum, required a high level of cognitive demand, and had to be difficult at that higher level of understanding.

Olympiad-type examinations provide a useful assessment of how the teacher thinks, and a means of moving the teacher along the path of selecting content of appropriate difficulty, anticipating the kinds of misconceptions that students might have, and checking that the goals and the assessment match. For this reason, Paul Black and Dylan Wiliam (1998) argue that assessment is not just a way of measuring learning. It is a strong lever to improve teaching. More experienced teachers who are familiar with good assessment can better identify the understanding of each student and adjust their teaching accordingly.

Another part of Olympiad preparation procedures is planning, which can be understood as organizing a curriculum, sequencing it, and/or adapting teaching and learning strategies. Darling-Hammond et al. (2017) see planning as a key part of

pedagogical knowledge in their model of pedagogical knowledge. Planning requires the integration of subject content knowledge (subject matter knowledge) and pedagogical knowledge. Olympiad-based learning requires the teacher to cover material beyond what the student might be expected to be able to understand.

Training camps and workshops may also provide teachers and students longer periods of working together to problem solve, engage in peer review, and receive feedback and mentoring. Kumar and Chaudhary (2018) found that structured training for teachers had a positive effect on student outcomes and teacher behavior. Another factor in preservice education studied by Mansur Tchoshanov and colleagues (2016) in fostering reflective teaching and metacognition is collaboratively developing lessons.

Competitions such as Olympiad competitions or problem solving workshops help teachers develop because by having teachers involved in organizing such competitions, the teachers are participating in leadership, teamwork, and professional development, because they are collaborating, networking, and learning to look at problems and solutions from other people's perspectives. This develops their content knowledge and helps them strengthen their organizational and interpersonal skills, which are important requirements of being a teacher.

Supplemental learning material is another way of teaching. Serious textbooks, online educational contents, and databases of problems can give students opportunities to supplement what they learn in the classroom with independent practice. According to Hattie (2009), there is a greater effect on student learning when there is a range of learning resources and support for students.

However, the efficiency of resource use depends greatly on how frequently the resource is used and how well it is employed for teaching and learning, otherwise it may overload or bore students. According to Schukajlow and Krug (2014), the use of resources is characterized by wise and targeted use and is attuned to the students' level and the content to be learned.

The Olympiad culture also includes peer-advising, where students talk to each other about their ideas about problems and problem-solving, and share their ideas for how to solve problems. This has the added benefit of being very valuable to teachers, who can incorporate their students' problem-solving strategies into their teaching. These interactions may eventually develop a community of practice that builds and refines different kinds of knowledge.

Despite the positive influences that Olympiad-related activities provide to the Olympiad students, these activities can have negative influences too. Robinson (2012) mentions that there are challenges to integrating Olympiad preparation into the normal school day and these include: time constraints, institutional and structural challenges and access to resources. There is existing literature that discusses these and other challenges in detail which makes it difficult to integrate these Olympiad-related activities into the school curricula.

Collectively these studies suggest the Olympiad preparation is a rich practice-based context in which teachers' and students' learning are mediated by a repertoire of pedagogical practices that afford teachers and students opportunities to engage in continued knowledge building, instructional refinement, and study of advanced content.

These activities must be separated out so we can understand how much Teacher Content Knowledge (TCK) and Student Achievement (SA) changes in response to activities. This way, we can know what parts of the Olympiad preparation in our study really help improve TCK, and impact SA in a meaningful way.

2.6 Research Gap and Conceptual Framework

Several studies have focused on teacher professional development, teacher knowledge as it relates to student learning outcomes, and the role of academic competitions in schools. However, there is little research focusing on in-service professional learning to improve teacher knowledge and practice within teaching and learning. There is a relationship between teacher knowledge and student learning outcomes, but little is known about the influence of practice-based high cognitive

demand activities, such as preparation for Physics Olympiads, on in-service teachers. Most studies have focused on the impacts of Olympiad programs on the participants. Generally, these studies find positive impacts on problem solving, critical, higher order thinking, and academic achievements (Kumar & Chaudhary, 2015, 2018; Schukajlow & Krug, 2014). There is some evidence of indirect teacher-level impact, but few systematic investigations have been conducted on the impacts of Olympiad participation on teachers.

Additionally, a predominant focus of research on teacher professional development has been on customary forms of professional development such as workshops, seminars, and formal professional development training (Desimone, 2009; Darling-Hammond et al., 2017) that have been shown to be useful but often do not provide for sustained change in teacher instructional practice over time. Little research has been conducted on embedded, practice-based professional development in which teachers receive professional development in their roles as participants in the instructional setting. Swanson et al. (2014) and Robinson (2012) find that coaching Science Olympiad generally does have the potential to improve teachers' science content knowledge and pedagogical content knowledge, but this is mostly qualitative evidence, and there is a need for more quantitative studies that find out how much participation in Olympiad activities may affect teacher learning.

It is tempting to think of Olympiad participation as a single variable. Olympiad practice consists of teaching Olympiad lessons, Olympiad training camps, Olympiad tests, the preparation of Olympiad-related lessons, the organization of Olympiad-related activities, and reading Olympiad-related books, articles, videos, and so on. These aspects differ from Olympiad preparation program to Olympiad preparation program. In terms of professional development and pupil learning, the precise influences of these aspects, separately and in combination, are less well known.

Furthermore, teacher academic development is not clearly related to student academic achievement in academic high-level tracks. Hill et al. (2008), Hattie (2009), and Rivkin et al. (2005) found that teacher academic knowledge was a strong predictor

of student academic achievement, but teacher academic development is not clearly related to student academic achievement. In competitions such as the Physics Olympiad where the outcomes of students depend also on their prior knowledge, motivation, ability and available resources, ignoring the teacher and student outcomes simultaneously will lead to the effect of teacher effectiveness being conflated with any other effects on student outcomes.

Second, there is a relative lack of literature relevant to this region in Central Asia. Most of the existing research focuses on western educational systems (which could differ vastly in their curriculum, pedagogies and other educational supports). A study of the factors of Olympiad preparation in Kazakhstan may also provide further perspective and potentially a more subtle and contextualized understanding of teacher development in the area of Science, Technology, Engineering and Mathematics (STEM) education.

Third, some of the studies reviewed to date may have relied too heavily on qualitative techniques (e.g., interviews, self-reports), which may not be the best methods for detecting complex, systematic, and statistically important relationships. Further developments may rely more on quantitative approaches (based on measurements and statistics) for their potential to offer richer insights into the phenomena under investigation.

Consequently, in this study, we proposed a theoretical model of Olympiad preparation activities, Teacher Content Knowledge (TCK) and Student Achievement (SA). Olympiad preparation activities, which were defined as a multi-dimensional construct, include a set of interrelated activities, such as teaching lessons, attending training camps, giving examinations, planning lessons, conducting academic activities, and using supplementary resources. These activities can be understood as independent variables which characterize different ways of participating in practice-based learning environments.

Teacher content knowledge (TCK) is the major research outcome. TCK, as the name suggests, refers to the extent to which teachers have more understanding about

physics concepts and teaching. TCK is expected to be positively affected by the degree of Olympiad-related activity because teachers are expected to deal with advanced physics content in personal learning and instruction. The second outcome variable in the model is SA, operationalized through the Olympiad results in physics. SA is expected to be directly affected by student-level variables such as learning environment access and indirectly through TEA, which positively influences the school-level quality.

More importantly, TCK mediates the relationships of Olympiad preparation activities with students' outcomes. Specifically, the use of resources has a positive direct relationship with students' outcomes. The use of TCK and the use of resources can be interpreted as the relationship between teacher-centered activities and student-centered activities in mathematic Olympiad training. The use of teacher-centered activities affects teacher professional development more directly and more strongly than the use of student-centered activities.

Informed by the present conceptual framework, the article investigates how Olympiad preparation is learned by students and teachers in relation to different dimensions of participating in Olympiads. By triangulating theory and empirical research on Olympiad preparation, we contribute theoretically and methodologically to the field of understanding Physics Olympiad preparation as a form of practice-based teacher professional development.

3 Research Design and Methodology

3.1 Research Method

A quantitative approach to research was used to measure the impact of Physics Olympiad preparation on the professional development of the teachers and the students' success in the achievement test. A quantitative approach was used in the study because of the advantage in showing how variables are related as well as the ability to apply statistical testing.

Data was collected from official educational resources, such as bil.org.kz and the electronic portal of the Government of the Republic of Kazakhstan, by compiling information about teachers and students for the purpose of studying the relationship between Olympiad preparation activities and students' academic performance.

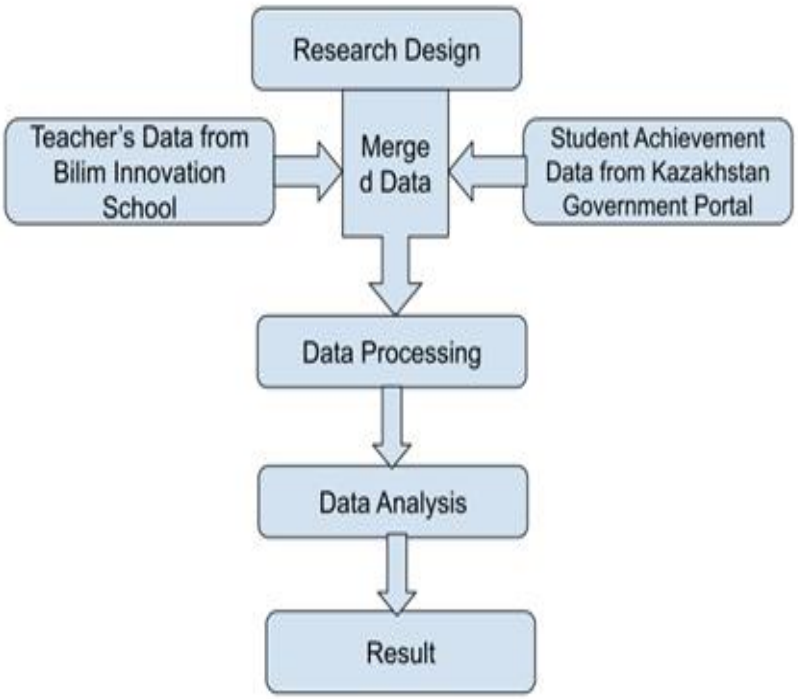


Figure 3.1.1 Research design

3.2 Sample

The participants in this study were physics teachers working at 23 Bilim Innovation Schools of Kazakhstan. Bilim Innovation Schools are elite schools for

highly gifted pupils who compete in Physics Olympiads at region, national, and international levels. Thus, the present sample was addressed as teaching in PGI teaching schools presents a context for understanding the relationship between Olympiad preparation and teacher professional learning, especially as PGI teachers are routinely exposed to higher-level academic and competitive training.

So that this study also used purposive sampling technique, the reason is that the type of sampling technique that the researcher used in this study was not a sample probability, but rather a sample of purposive sampling technique because this study was about schools and teachers that participate in Olympiad. The sample is not random, but it is appropriate for investigating specialized teaching of a subject when the Olympiad is a pedagogical tool.

Thus, teachers were first categorized into four quality levels according to the ratings made by the trained teacher-evaluators from the teacher sample of the study, who were required to rate their teacher quality with respect to several important instructional and professional dimensions relating to Olympiad preparation. It was defined as follows:

- Group 1: 0 to 40 (low level of performance)
- Group 2: 41-65 (moderate level of performance)
- Group 3: 66-90 (high level of performance)
- Group 4: 91-100 (very high level of performance)

Table 3.2.1 The Grouping of Teachers based on OPA subdomains

Domains	**Group**	**Score interval over 100 points**	**N**
Lesson conducted	1= No	0-40	5
	2 = Somewhat	41-65	0
	3 = Mostly	66-90	11
	4 = Complete	91-100	7

Olympiad Camp	1= No	0-40	4
	2 = Somewhat	41-65	3
	3 = Mostly	66-90	10
	4 = Completely	91-100	6
Periodic Exam	1= No	0-40	4
	2 = Somewhat	41-65	0
	3 = Mostly	66-90	16
	4 = Completely	91-100	3
Planning	1= No	0-40	4
	2 = Somewhat	41-65	5
	3 = Mostly	66-90	8
	4 = Completely	91-100	6
Events	1= No	0-40	4
	2 = Somewhat	41-65	5
	3 = Mostly	66-90	9
	4 = Completely	91-100	5
Resources	1= No	0-40	5
	2 = Somewhat	41-65	5
	3 = Mostly	66-90	6
	4 = Completely	91-100	7

This stratification made it possible to compare teachers with higher or lower levels of engagement and effectiveness to identify differences in content knowledge and instructional practices and how these vary with differences in student achievement between groups with different placements.

Grouped sampling can be used as a useful feature for other types of statistical analyzes such as ANOVA, which seeks to test for differences in means between groups. This theory is used to test if higher levels of Olympiad preparation lead to better teacher and student performance.

Ultimately, a limitation to the generalizability of the sample, but the sample is appropriate and relevant to the study of the research question. The findings are only broadly generalizable to intense school systems with a focus on training for Physics Olympiad competition. However, the study was able to find how structured school and teacher-specific activity can influence teacher PD and student achievement.

3.3 Data Collection Tools

In addition, this study was supported by different data collection instruments. The use of different instruments increases the validity and reliability of the findings in the study, as the research problem is studied from different angles, which increases data triangulation of the fulfillment of teachers' performance and student achievement.

The official and standardized sources of information were educational website bil.org.kz and e-portal of the Government of the Republic of Kazakhstan, which were selected based on their ability to provide structured and verified information regarding teacher assessments of students' knowledge during the Physics Olympiads at the national and international levels.

The three primary tools used in data collection were the Teacher Assessment Test (TAT), the Olympiad Preparation Activities (OPA) framework, and the students' achievement records.

The Teacher Assessment Test (TAT) was used to measure teachers' content knowledge (TCK) in physics. It was a 40-item multiple choice exam with five response options for each question and a maximum possible score of 100. The test was developed to assess the content knowledge contained in the national secondary school physics curriculum (natural science curriculum: grades 7-11) and to assess the skills of real, practicing physics teachers. The test also provided a standardized assessment of physics teachers' subject matter knowledge and their use of such knowledge to solve problems.

The Olympiad Preparation Activities (OPA) framework was used to determine the Olympiad-specific teaching skills of teachers in this study. Six subdomains were identified: lesson delivery, Olympiad camps, periodic examinations, planning, events,

and the utilization of resources. The subdomains are related to content delivery, organization and resources, etc. Trained evaluators then gave each teacher an annual, domain-spanning score from 0 to 100 based on strict descriptors within the subdomain. The evaluation captures the extent and effectiveness of the teacher's contribution to the Olympiad preparation through their participation.

The official pedagogical activities included in the OPA include offering classes on specialized subjects, planning and participating in training camps or competitions, evaluating students' suitability for advancement into competitions, creating lesson plans for classes, preparing for course-related events, and providing materials, such as books and electronic resources. These activities are related to the grooming of students for advanced academic preparation.

The data on students' performances were obtained through the official results of the regional, national and international Physics Olympiads. The present study focused on stage-3 and stage-4 of the Olympiad system, which are characterized by higher competition and academic achievement. Olympiads are typically divided into four rounds: school, district or city, regional and national. In the final round, approximately 45% of the participants receive first, second, and third degree diplomas.

These three data sources include input variables, such as teacher knowledge and use of instructional strategies, and output variables, such as student performance. Their triangulation allows a more thorough investigation of the relationships between teacher professional development, use of instructional strategies, and student academic performance in the Physics Olympiad preparation context.

3.4 Data Analysis Methods

Data was analyzed using SPSS (Statistical Package for the Social Sciences), a statistical package which allows for the analysis of wide-ranging data sets and complex statistical procedures in educational research. The analysis had several stages, including reliability and validity testing, and allows for an understanding of the relationships between the variables.

In the first stage, data preparation and data cleaning were performed by combining the datasets of the students who were related to the teachers and the dataset related to students' achievement. The two datasets were combined into one and analyzed in terms of the relationship between TCK, OPA and students' achievement.

Prior to performing the inferential statistical tests, the assumptions regarding parametric tests were checked using Levene's test for homogeneity of variances. The equality of variances among the groups of the independent variable (homogeneity of variance) is an assumption of analysis of variance (ANOVA). According to Levene's test for equality of variances, the variances among the groups were shown to not considerably differ ($p > 0.05$) from one another. Since this showed the variances were homogeneous, the assumption for ANOVA was satisfied and ANOVA could be applied.

A one factor Analysis of Variance (ANOVA) was used to test whether there were statistically important differences between groups of teachers, in terms of their performance levels. Analysis of variance is a statistical technique used to determine if this type of difference between groups has occurred by chance, when the means of more than two groups are compared. ANOVA was used to compare each level of Teacher Content Knowledge (TCK), Olympiad Preparation Activities (OPA) and Student Achievement (SA) and the four groups according to the class medians.

In this case, the ANOVA test was able to detect that not all four groups were sampled from populations with the same mean score. The ANOVA test cannot, however, tell us which groups have different mean scores. A post hoc analysis using the LSD test (Least Meaningful Difference) was run for these differences to determine which groups were considerably different from the others (where the important differences were). This step made the relationship between teacher performance levels and differences in content knowledge, teaching, and student outcomes more subtle and clearer.

In addition to conducting the post hoc analysis, a Homogeneous Subsets analysis was conducted. A Homogeneous Subsets analysis divides the data into groups with the

same mean but further divides them into more specific subgroups, which tell which groups are more similar to each other, as compared to other groups, in order to yield a more meaningful analysis of the effect of levels of teacher engagement on the KPI of interest, within pupil groups.

The combination of these statistics provides a systematic methodology for analyzing the relationship between professional learning and student achievement. By including SPSS as the platform for conducting these calculations, assumption testing, ANOVA, post hoc, and subset analysis are used to create a reliable and thorough analysis of the research. As such, this study was able to draw valid conclusions as to how the preparation for the Physics Olympiad affected teachers and students.

4 Analysis and Results

4.1 Preliminary Analysis: Test of Homogeneity of Variances

Prior to conducting inferential statistical analyzes, it is a good idea to test the underlying assumptions of a given statistical test with the data. For the case of the ANOVA statistical test, one of the most important underlying assumptions of the data is the assumption of homogeneity of variances, which states that the variability around the mean across groups is equal. Because violation of this assumption can produce biased results, it should be checked prior to conducting any further analysis.

Levene's test for equality of variances was used to confirm or reject the assumption of homoscedasticity, which states that the variance of the dependent variable must be similar across groups. These research variables were therefore tested for homogeneity of variance as follows: Lesson Delivery (LD); Professional Competence (PC); Teacher Content Knowledge (TCK); and Student Achievement (SA).The results of Levene's test are presented in Table 4.1.1.

Table 4.1.1 Test of Homogeneity of Variances

Scale	Sig.
Delivery Lesson	.977
Prof Competence	.908
TCK	.738
SA	.236

In summary, as shown in Table 4.1.1, the Lesson Delivery (Sig =.977), Professional Competence (Sig =.908), Teacher Content Knowledge (TCK) (Sig =.738), Student Achievement (SA) (Sig =.236) are all greater than .05 which implies

there are no meaningful results. As the p-values are all greater than .05, the null hypothesis of equal variances cannot be rejected.

It can hence be concluded from the analysis that groups do not considerably differ in terms of variance. This means that assumptions of homogeneity of variances are met for all variables tested. Statistical analysis of the data using parametric statistical tests is safe and valid, for example, by one-way ANOVA and post hoc tests.

Testing for homogeneity of the variances between groups is important, as it legitimizes the results of statistical tests. If there are differences between the groups, it can be assumed that these differences are due to true group differences and are not simply differences in variance across the groups.

4.2 Lesson Delivery Effect on Teacher Content Knowledge (TCK) and Student Achievement (SA)

Section 4.1 analyzes the effect of the lesson delivery treatment on the TCK and SA dependent variables. The section is designed to show differences in the content knowledge of teachers who differ in the level of engagement in delivering the Olympiad lesson, and whether this translates into differences in the students' performance in Physics Olympiad.

Teachers were then categorized in one of four groups based on their instruction of Olympiad lessons, with those that did not deliver Olympiad lessons in the first group, those that delivered Olympiad lessons somewhat in the second group, those that delivered Olympiad lessons mostly in the third group, and those that delivered Olympiad lessons completely in the fourth group. This classification shows the steps in terms of the instructional engagement of the teachers. Within this classification, different levels of engagement can be compared for teacher and student outcomes.

To assess the combined effect of delivery mode on both outcome variables, a multivariate analysis was performed. No multivariate effect of delivery mode on the combined TCK and SA dependent variables was found. Wilks' lambda, $\lambda = 0.827$ (> 0.05), indicates that in a one-time comparison, there are no meaningful differences in the lesson delivery method of the four groups, namely, sheltered approach, integrated

approach, complementary approach, and non-approach. The result implies that the lesson delivery method does not considerably affect teacher knowledge and student achievement.

Still, the differences between dependent variables are meaningful when analyzed separately with post hoc comparisons using the Least Important Difference (LSD) test to determine differences between specific pairs. This provides for a set of pairwise comparisons amongst groups so that the specific differences between groups can be detected for multivariate test.

For Teacher Content Knowledge (TCK), there was a statistically meaningful difference between teachers who did not deliver the Olympiad lessons and teachers who completely delivered the Olympiad lessons. In comparison to teachers who did not deliver Olympiad lessons, teachers who completely delivered Olympiad lessons had a TCK mean difference of -17.9286 ($p = 0.049$) which was considered to be statistically considerably different. This suggests that the involvement of teachers in instruction may be important for subject knowledge.

From a teaching perspective, it could also be argued that Olympiad level mathematics requires teachers to learn the theory, solve the problems and expect the more diverse potential student responses, which might result in a greater level of teacher cognitive engagement, reinforce the learning of concepts and generalization of mathematical knowledge for the teacher. Teachers that take a full role in teaching the lesson are the ones that receive the benefits from this.

Likewise, analysis of Student Achievement (SA) reveals that the lesson delivery groups do not differ considerably ($p > 0.05$). In other words, although the lesson delivery levels may be of different types, this does not have important impact or influence on students' performance in Olympiad level assessments. However, their increased subject matter knowledge appears insufficient to produce statistically important impacts on student achievement in the existing studies.

The gap between TCK and SA outcomes suggests an interesting aspect of the educational process.

Student outcomes are also influenced by student motivation and preparation, student ability, and classroom context. Thus, while lesson delivery is one component of teacher development, it is only one piece in the larger puzzle and would not be expected to have any direct effect on student outcomes above and beyond the effects of confounding variables.

The results of the above pairwise comparisons are shown in Table 3. TCK group differences and SA group differences are included in the comparison table..

Table 4.2.1 Lesson Delivery Effect on TCK and SA

Dependent Variable	(I) Lesson	(J) Lesson	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
TCK	1.00	3.00	-13.3182	5.92248	.088	-29.7616	3.1253
		4.00	-17.9286*	6.42956	.049	-35.7799	-.0772
	3.00	1.00	13.3182	5.92248	.088	-3.1253	29.7616
		4.00	-4.6104	5.30904	.434	-19.3506	10.1299
	4.00	1.00	17.9286*	6.42956	.049	.0772	35.7799
		3.00	4.6104	5.30904	.434	-10.1299	19.3506
SA	1.00	3.00	-3.4364	2.81123	.289	-11.2416	4.3689
		4.00	-.0857	3.05193	.979	-8.5592	8.3878
	3.00	1.00	3.4364	2.81123	.289	-4.3689	11.2416
		4.00	3.3506	2.52005	.254	-3.6461	10.3474
	4.00	1.00	.0857	3.05193	.979	-8.3878	8.5592
		3.00	-3.3506	2.52005	.254	-10.3474	3.6461

*Note: Based on observed means. The error term is Mean Square(Error) = 27.167. *. The mean difference is significant at the .05 level*

These findings suggest that lesson delivery has a positive impact on teachers' content knowledge, and at the highest teacher engagement level, lesson delivery has a meaningful impact on teachers' content knowledge. However, lesson delivery did not have a meaningful impact on student achievement, so increased teacher content knowledge per se may not be a sufficient condition for improving student outcomes in Olympiad settings. The researchers note that the link between teaching practices and student achievement is complex, and further research is needed to examine the role of other factors..

4.3 Olympiad Camp Effect on Teacher Content Knowledge (TCK) and Student Achievement (SA)

In this section, we will explore the potential mediation effect of teachers, who assume the responsibility of leading and managing Olympiad camps. The dependent variables measured are Teacher Content Knowledge (TCK) and Student Achievement (SA). Olympiad camps, which involve some organized training with problems as well as high-level competitions, are also expected to have some positive impact on teacher preparation and on pupils' educational experience and achievement.

Teachers were grouped according to whether they participated in Olympiad camps, which was classified as none, somewhat, mostly, and complete based on the level of participation. Teachers were divided into these groups based on their level of participation in Olympiad camps, which indicates different levels of exposure to an intensive academic environment, in order to observe the effect of teacher involvement on teacher knowledge and students' performances.

In the same study, a multivariate test analyzed the effects of Olympiad camp participation on TCK and SA. This multivariate test found that Olympiad camp participation did not have a statistically meaningful impact on TCK and SA (Wilks' lambda = 0.904, Sig = 0.943). In summary, based on these results, Olympiad camp participation generally has no effect on the combined distribution of teacher content knowledge and student achievement.

However, LSD post hoc analysis at the variable level found statistically important differences for several of the 10 variables, such as Teacher Content Knowledge (TCK). A statistically important mean difference of 8.38655 ($p = 0.038$, $N = 25$) was found between teachers who did not participate in organizing Olympiad camps and those who participated to a limited extent (somewhat). In another measure, teachers not involved in organizing Olympiad camps were compared with teachers involved in organizing Olympiad camps; a mean difference of 7.08793 ($p = 0.022$) was found.

The results of this study show that even partial involvement in Olympiad camps is associated with a positive growth in teachers' content knowledge, likely due to their exposure to problem solving, constructionist learning, team learning environments, and elevated discourse with mathematicians. This exposure can improve their knowledge of physics at the most advanced level, and thus, their ability to teach it.

Theoretically, this finding supports the notion that teacher learning is contextualized within practice. Olympiad camps expose teachers to experienced teachers and others' teaching practices through their own lenses; this involves observing and reflecting on what other teachers do in carefully designed lessons. This aligns with constructivist and experiential learning theories, which suggest that professionals learn best by actively participating in real-world experiences.

However, Student Achievement (SA) did not differ among the three groups (all $p > .05$), meaning that the participation of teachers in Olympiad camps does not positively or negatively affect student achievement in a statistically important way, according to the results of this study.

This shows how multifactorial the correlations between teacher and student performance on Olympiads are. Student performance is not only dependent on teacher knowledge, but also on student factors such as intelligence, motivation, prior training, and intensity of student training. As a result, a statistically important difference in student performance from teacher skill increases from Olympiad camps may not exist.

Furthermore, benefits to the Olympiad camps' teachers may be indirect and lagged, because teachers may incorporate pedagogical practices from the Olympiad camps in their classes only gradually, or may do so most effectively only in the teaching of subsequent cohorts of students. This may not be captured by cross-sectional studies of teacher effects above.

Overall, there is evidence that Olympiad camps had a positive effect on Teacher Content Knowledge regardless of the teacher's level of Olympiad participation. However, there is no evidence of a statistically important impact of Olympiad camps on Student Achievement using this dataset. Taken together, these findings support the conclusion that professional development is effective in improving the knowledge and skills of a teacher, but less clear in improving student achievement.

4.4 Effect of Conducting Olympiad Exams, Planning, Organizing Events, and Using Resources

This section was developed based on the analysis performed to discover the effect of four independent variables of Olympiad preparation: Olympiad exams conducted, design of teaching strategies and thoughts, organization of academic activities, and preparation of supplementary learning materials. These four independent variables are used to quantify the four aspects of the teacher's professional practice in Olympiad preparation, and they are included to examine their combined effect on TCK and SA in Olympiad preparation.

While the previous parts were dedicated to individual variables, in this section, we aim at examining a broader scope of variables, making it possible to consider Olympiad activities as a part of the entire educational process. Each variable is a single type of cognitive/professional activity: conducting exams involves building tasks and evaluating students' answers, planning means teaching and structuring the pedagogical process, organizing events involves leading and cooperating with colleagues, and using resources means adding and utilizing additional educational material.

A multivariate analysis was then employed to test whether the above variables had a statistically important effect on the two dependent variables TCK and SA when

considered together. No statistically important multivariate effect was obtained in this case, as all p-values associated with the Wilks' lambda statistic were above the 0.05 importance level. This suggests that, in a combined statistical model, these variables do not have a meaningful joint effect on both teacher knowledge and student performance.

However, this does not mean that no important relationships exist; further analysis of each of the variables can show relationships that are omitted from the multivariate importance test. To explore these patterns in more detail, a Least Important Difference (LSD) post hoc analysis was run comparing the different levels of teacher engagement.

There was a statistically important effect of Teacher Content Knowledge between teachers who were not conducting the variable Olympiad exam and teachers who were completely engaged in conducting Olympiad exams (mean difference = -34.7917, p = 0.014). This is one of the largest differences in our dataset, which suggests that activities that involve assessment of student performance are especially important for teacher development.

This is, in part, explained by the demands of the exam preparation: teachers who design and administer Olympiad exams need a deep understanding of the subject matter, an ability to evaluate problem difficulty and anticipate possible students' approaches, and a match between the problems and learning goals. Teacher-participants in creating Olympiad assessments engage in high-level pedagogical work. They engage in the development of knowledge for teaching, particularly when repeatedly engaged in that work and working to identify and address common student difficulties with important content.

The variables planned and monitored a given day of planning statistically considerably influenced TCK. Statistically meaningful differences were found in mean TCK between teachers who did not plan and those who planned to a somewhat (-20.8750, p = 0.047), mostly (-20.6250, p = 0.037) or completely (-21.0417, p = 0.041) higher extent.

Thus, the results suggest that planning is not just an administrative task, but a cognitively demanding activity that contributes to teachers' professional growth.

Planning has educational components: selecting content, sequencing, anticipating students' misconceptions, and aligning instruction with educational goals. While teachers participate in planning, it should also generate reflection about the teacher's decisions, consideration of alternative instructional approaches, a deeper understanding of the content, and an understanding of the process of teaching and learning. Planning is therefore an important means of moving from theoretical knowledge to the practical ability to teach.

A statistically meaningful difference was determined in TCK when comparing those teachers who organized academic events with those who did not. Non-organizers had considerably lower content knowledge than teachers who organized events completely by -25.8750, ($p = 0.025$). There was also an important difference between teachers who mostly organized events and teachers who only organized events (-24.5556, $p = 0.016$).

Olympiad competitions, workshops, training camps and other mathematics-related academic activities require teachers to work collaboratively with peers, to interact with other teachers, to encounter different problem-solving approaches, and to deal with high-level mathematics content. These events can support the development of teachers' professional knowledge and provide an opportunity to discuss and reflect on their ideas about effective mathematics instruction. This provides evidence that working collectively and learning through experience is effective for professional development.

However, the items for conducting exams, planning, and organizing activities were all statistically non-important for the Student Achievement (SA) outcome ($p > 0.05$), despite the statistically meaningful effect of these items on teachers' content knowledge. This finding implies that while the training is effective in improving teachers' subject matter expertise, it does not have a statistically measurable impact on student achievement.

But, as this example shows, gains in teacher knowledge need not translate directly into gains in student achievement. Student performance results from a mixture of ability, motivation, prior knowledge, learning strategies, and time on task. Thus, improving teachers' knowledge does not automatically translate into improved achievement for the students they serve. Therefore, while teacher development may be a necessary condition for improving student outcomes, it may not be a sufficient condition.

Whereas different patterns were found for the number of resources that were used, no important differences were found between groups for Teacher Content Knowledge. However, a statistically meaningful effect was found for Student Achievement, with a 9.4000 ($p = 0.046$) mean difference found between students whose teachers somewhat used resources and students whose teachers did not use resources. There was also a mean difference of 11.9333 ($p = 0.019$) between students whose teachers somewhat used the resources and students whose teachers used the resources most.

The studies suggest that it may be the logistics of resource use that matters. Greater access to resources, such as advanced textbooks and use of online or problem bank resources work because students have more types of problems and independent practice to use as reference beyond implicit assumptions. Resource material usage is different from teacher-centered activities that directly improve professional capabilities.

It has important implications for education, because it shows that Olympiad preparation activities have different outcomes depending on the type of activity.

Teacher centered activities, such as giving students exams, planning and organizing, have more influence on teacher professionalism and knowledge. Student centered activities, such as providing students with more resources, have more influence on student performance.

If we consider these together, we see here a macro-level analysis of Olympiad preparation: different dimensions of Olympiad preparation influence different layers

of the educational system and have different effects on various outcomes. While some activities are more helpful to teacher development, others are more strongly associated with improved student performance.

This indicates that Olympiad program design must strike a balance by ensuring that teacher professional development and student learning opportunities are provided together so that overall effectiveness of the Olympiad program is maximized, and the program's short- and long-term contributions to improving teaching and learning can be sustained better.

5 Discussion

This study focuses on the relationship between participation in PO-preparation practice and the professional development of in-service physics teachers as well as students' academic performance. The results show several ways in which teachers' participation in different forms of Olympiad-preparation practice is related to their knowledge and instructional practice and, to a lesser extent, students' achievement. Overall, the results suggest that Olympiad preparation is a promising form of teacher professional learning, and one of the biggest challenges is measuring the impact of teacher-learning on student outcomes.

The major conclusion of the study is that TCK was greatly improved when the teachers were engaged in Olympiad activities (teaching Olympiad lessons, preparing Olympiad camps and Olympiad papers and running Olympiad competitions). So, we can suggest that TCK development can be promoted when teachers are engaged in cognitively demanding teaching practices. Teachers may have better knowledge of their subject compared to Olympiad problems, and teaching Olympiad material may then help teachers learn their subject better.

PCK is consistent with Shulman's (1986) definition and Hill et al.'s (2008) operationalization of pedagogical content knowledge. The PCK framework assumes that the knowledge of content and the knowledge of pedagogy need to be optimally integrated so that teachers know how to present content at the appropriate level of difficulty that is understandable and meaningful to learners. Olympiad preparation provides exactly such a context through the need for teachers to deal with advanced topics in physics, to design competition problems, and to explain advanced concepts to gifted students.

The Olympiad preparation experience supported the idea that practice-based PD was more effective than PD that remained largely theoretical. Teachers engaged in a form of instructional problem solving that occurred over a longer time scale as opposed to the focused time period of a workshop or lecture. This adds support to Desimone

(2009) in that powerful professional development is targeted, active, and closely aligned with the practice of teaching in the classroom.

Results from the study also supported the Olympiad camps, which encouraged teacher reflection, mentoring, and difficult problems for students. Because teacher experiences such as these promote content growth and reflection, as well as collaborative planning, they are aligned with Tchoshanov, Lesser, and Salazar (2016), who found teachers' and students' participation in high level academic work led to better metacognitive awareness and design of instruction.

However, managing and organizing academic events had a strong impact on TCK, requiring knowledge of how to organize learning experiences, anticipate student learning needs, and integrate complex academic processes. Theoretically, Stein et al. (2008) argue that teacher learning around cognitively demanding tasks requires pedagogical reasoning and a form of pedagogical reasoning that includes the ability to design scaffolding for cognitively demanding tasks. The argument that teacher learning is tied to the planning of cognitively demanding tasks provides a strong basis for supporting teacher development.

I found that Olympiad preparation contributed to teacher learning but had no effect, or even an inverse effect, on Student Achievement (SA). The lack of relationship between teacher learning and SA was one of the most important findings of the study and illustrates the complexity of educational processes.

One interpretation of these findings is that student outcomes are jointly determined by many variables, including students' prior knowledge, their motivation and cognitive ability, as well as the amount of practice students engage in. Teacher expertise is also one of these variables, but seems to be insufficient, at least by itself, to produce short-run outcomes. Dori and Belcher (2005) have also stated that teacher knowledge is a prerequisite to effective teaching, but that alignment in curriculum, instruction, and assessment are also necessary.

A second possible explanation is that teacher professional development is followed through fairly quickly in the intensive levels of Olympiad preparation

analyzed in this article, whereas the student achievement effects identified in this article arise as a result of long term instruction and practice. Smith, Miller and Thomas (2019) have suggested that the effects of teacher professional development are likely to be more longitudinal impacts that will only become apparent when such professional development has become embedded. However, teacher development based on participation in the Olympiad is unlikely to be cross-sectional.

More specifically, a close link was found between the use of resources and students' learning outcomes. A number of direct learning support mechanisms, such as teachers using high-level textbooks, the use of online resources and problem-based environments, best predicted students' learning achievement. This suggests that teacher-centered activities are more effective at developing teachers, while student-centered activities are more effective for improving student learning outcomes in the short term.

These findings also support the hypothesis of an optimal level of resource usage. Schukajlow and Krug (2014) propose that a balanced presentation of related or unrelated problem solving tasks might contribute to students' learning and persistence in mathematics. Quantity matters. Too much advanced material or too little could overload or underload students' cognitive processes and affect the development of automatization. Therefore, the optimal amount of resource utilization and quality are a function of both.

Furthermore, the study findings support prior research on teacher professional development models that are less effective, due to their theoretical foundations and time-limited interventions. Conversely, Olympiad training as a model can be described as a practice-based, situated program, in terms of its reliance on content knowledge, pedagogy, and practice through real-life application. This echoes the findings of Swanson, Wilson and Medinilla (2014) on the effectiveness of experiential learning.

A key starting point would be to provide policymakers with research evidence, as this study has done, that Olympiad training may be an avenue for scaling up high quality teaching and learning of STEM in schools. Olympiad training may be a key

strategy to address the chronic shortage of trained physics teachers (The Royal Society, 2007; Oon & Subramaniam, 2011) in a curriculum relevant, continuing and high quality manner.

Finally, teachers' time commitments, lack of institutionalized support for teachers in the school setting, and lack of recognition for teacher participation in Olympiad-based professional development may continue to obstruct Olympiad-based teacher professional development.Overcoming these barriers and supporting these programs may enable their further development and maintenance at scale.

These findings can inform longitudinal studies of the effects of Olympiad preparation on teacher learning and student outcomes, or mixed methods studies on the cognitive and affective aspects of teacher learning in the context of Olympiad preparation. Future research can also be conducted in different educational systems and cultural contexts to explore potentially helpful cultural and institutional factors affecting Olympiad-based professional development.

It is difficult to dispute the high influence of preparation for the Physics Olympiads on teachers' vocational knowledge and practical skills described in the paper. The research community knows little about the influence of the Physics Olympiads on students' performance, especially when it comes to the collection of external and internal factors affecting this performance. There must be a balance between teaching and learning.

6 Conclusion

This study employed a mixed-methods approach to examine the extent to which the PO preparedness of in-service physics teachers may inform their professional development and their students' academic performance. The study found the effect of in-service teachers' PO preparedness on Teacher Content Knowledge (TCK) to be statistically meaningful and consistent. Activities related to Olympiad preparation (lessons, camps, plans, events) seem to have an effect on TCK in a positive direction. Additionally, results suggested that teachers' academic knowledge for higher-order practices and pedagogical practices was positively associated with TCK.

The main contribution of this study was the characterization of Olympiad training as the school-based apprenticeship model of teacher professional development, that is, teachers of students who received intensive Olympiad training had better conceptual understanding, better reasoning abilities and better knowledge of pedagogical content than teachers of students with no Olympiad training. These findings add to the research base supporting contemporary teacher learning models indicating the value of authentic, cognitively demanding contexts for sustainable teacher learning.

In contrast, the impact of teacher development programs on SA was more complex. Teachers showed stronger gains in knowledge, while findings on the related effects of PD on student learning were weak or not statistically important. This may indicate that teacher knowledge is an important part of the puzzle, but it has the strongest impact when combined with other factors, such as aligned teaching, engaged students, and resource accessibility.

The only statistically meaningful positive effect of additional educational inputs in the classroom was on student learning outcomes. Overall, direct learning support mechanisms appear to be more sensitive to resource availability than teacher-centered activities in their effect on student learning outcomes in low- and middle-income countries (LMICs). The results further suggest that moderate and goal oriented

supplement use has a better effect on performance than supplement under-utilization or supplement over-utilization.

It also has the implication that there might necessarily be a lag in time between changes in the teacher's professional development and changes in student learning and performance. In other words, the teacher needs to change first before student performance is likely to change. Olympiad-style teaching and learning are time-intensive, supporting the idea that improvement in education is a slow process of alignment and refinement.

In practical terms, these findings suggest that Olympiad preparation yields a sustainable and scalable model of teacher professional development in STEM education, which may be implemented as part of regular professional development programming in school systems. Olympiad preparation may offer frameworks to support teachers within a community of collaboration and innovation.

Nevertheless, potential constraints to implementation of the Olympiad-based professional development schemes emerged, including the availability of time, lack of institutional support and lack of recognition and reward of teachers' efforts to prepare students for Olympiads. Such constraints could be overcome to sustain and implement the Olympiad-based professional development schemes effectively.

These results have theoretical and practical implications for the growing body of work which argues for practice-based and content-rich models of teacher education that highlight the role of experiential learning in the pre-service teacher professionalization process.

Thus, it may prompt policymakers and the education community to consider Olympiad preparation as a possible option of improving physics education through a focus on teacher quality.

Ultimately, the approach taken to preparing students for the Physics Olympiad can have a strong positive impact on many of the issues affecting physics education. The development of cognitive and practical skills in students, as well as creating

communities of practice and professionalization points for teachers, could help improve and sustain STEM education.

7 Limitations

Ultimately, this study contributes valuable insights into the role of Physics Olympiad preparation in teacher professional development and student performance, though some limitations must be acknowledged in order to encourage future research and enable interpretation of the results.

Finally, since the data were cross-sectional, the researchers are not able to make certain about the causal relationship that could be drawn from these variables. Though the results were meaningful, it could not be determined whether the TCK and SA were caused by Olympiad preparation activities. A longitudinal study might also show how the TCK and SA relationship has developed over time and how the two variables influence each other, depending on the design of the longitudinal study.

Second, a possible limitation of this research is that the sample was limited to teachers from only the 23 Bilim Innovation Schools in Kazakhstan. Although the Bilim Innovation Schools would have been an appropriate context to focus on due to their emphasis on Olympiad, the results may not be generalizable. Differences in curricula, teaching practices, and institutional support across regions and countries could limit the transferability of the findings.

Third, we measure outcomes using secondary data, such as teacher evaluation scores and official Olympiad results. These data are likely reliable and valid measures, but miss many dimensions of teachers' learning and teaching. Variables such as teaching style or teacher-student interaction, teacher-student relations, and working environment were not measured in this study, although these could be examined in future research using qualitative approaches such as interviews or class observations.

Another problem with the SA toward the end of the competition was that Olympiad results were the major determinant of the SA. Though Olympiad results may be indicative of the ability to perform at a high academic level, they may not correlate with overall academic success of students. Factors such as individual ability, motivation and prior knowledge that are considered to be involved in Olympiad success were neglected in the study.

Because they were all cross-sectional evaluations, it is not possible to say from these studies whether better professional development would improve student academic achievement, and whether any such improvement would take time to come into effect. Future studies can contribute to this evidence base by including longitudinal designs that examine the association between teacher professional development and student academic achievement over time.

Furthermore, while we considered several Olympiad-related factors, we cannot really attribute their independent contributions to our results as most Olympiad-related factors are inextricably related and it is difficult to disentangle the contribution of any one of these factors. More advanced statistical models or experimental designs might help clarify these dynamics.

Last, since the study was mainly quantitative, the contextual and psychological factors of teachers' engagement in training students for the Olympiads were not treated in depth. Teacher factors such as motivation and workload, as well as school factors such as support and recognition of Olympiad activities, may contribute to teachers' involvement and performance. Future research may also include these dimensions to increase the understanding of the field.

Despite the limitations of this study, findings have provided empirical evidence regarding the importance of Olympiad preparation in pedagogy. These findings may be further substantiated, should limitations of this study be remediated in future research, which may provide evidence supporting a more effective and holistic approach to pedagogy.

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APPENDIX

Appendix A. *Definition of the Six Subdomains of the Olympiad Preparation Activities (OPA)*

Subdomains	Definition
Conducting Lessons	Providing planned Olympiad-level mathematics lessons appropriate for students' needs, with a minimum frequency of once a week.
Organizing Olympiad Camps	Conducting Olympiad camps, including different formats such as one-day camps, two-week camps, and intensive preparation sessions where students stay together for several days for full immersion into intensive study.
Administering Periodic Exams	Conducting exams after completing a major Olympiad-level topic to assess and evaluate students' understanding. These exams consist of open-ended problem-solving questions.
Setting Plans	Helping Olympiad-level students set clear, measurable, and achievable academic goals throughout the year, ensuring consistent progress and peak performance in competitions.
Extracurricular Events	The frequency and variety of activities aimed at boosting students' morale and motivation outside of lessons, such as organizing picnics, tea/coffee sessions, inviting guest speakers, or hosting joint camps with other schools.
Extra Resources	The extent of using additional Olympiad-level books and online resources. Includes offering at least one supplementary lesson per week, distinct from traditional lessons and regular instruction.

Appendix B. *Evaluation Rubrics for the Olympiad Preparation Activities (OPA)*

Olympiad Preparation Activities (OPA)	0%	40%	65%	85%	100%
Conducting Lessons	Does not conduct lessons	Conducts lessons once per quarter	Conducts lessons once per month	Conducts lessons once every two weeks	Conducts lessons every week
Organizing Olympiad Camps	Does not organize	Organizes once per quarter	Organizes once per month	Organizes once every two weeks	Organizes every week
Administering Periodic Exams	Does not administer	Administers once per quarter	Administers once per month	Administers once every two weeks	Administer every week
Setting goals	Does not set goals at all	Set goals for a few students	Sets goals for majority students, but does not monitor progress	Sets goals for all of of students, but does not monitor progress	Sets goals for all students and sticks to them

Extracurricular events	Does not organize	Organizes once per quarter	Organizes once per month	Organizes once every two weeks	Organizes every week
Utilizing Extra Resources	Does not use external resources	Uses external resources once per quarter	Uses external resources once per month	Uses external resources once every two weeks	Uses external resources every week

Appendix C. *Effect of Organizing Olympiad Camps on Teacher Content Knowledge (TCK) and Student Achievement (SA)*

(I) Group	(J) Group	Mean Difference (I-J)	*SE*	*Sig.*	95% CI Lower	95% CI Upper
Teacher Content Knowledge (TCK)						
1	2	-25.63*	8.39	.038	-48.91	-2.34
1	3	-13.63	6.50	.104	-31.66	4.41
1	4	-25.63*	7.09	.022	-45.30	-5.95
2	1	25.63*	8.39	.038	2.34	48.91
2	3	12.00	7.23	.172	-8.07	32.07
2	4	0.00	7.76	1.000	-21.56	21.56
3	1	13.63	6.50	.104	-4.41	31.66
3	2	-12.00	7.23	.172	-32.07	8.07
3	4	-12.00	5.67	.102	-27.74	3.74
4	1	25.63*	7.09	.022	5.95	45.30
4	2	0.00	7.76	1.000	-21.56	21.56
4	3	12.00	5.67	.102	-3.74	27.74
Student Achievement (SA)						
1	2	-2.67	3.98	.540	-13.72	8.39
1	3	-5.80	3.08	.133	-14.36	2.76
1	4	-3.83	3.36	.318	-13.17	5.51
2	1	2.67	3.98	.540	-8.39	13.72

2	3	-3.13	3.43	.413	-12.66	6.39
2	4	-1.17	3.69	.767	-11.40	9.07
3	1	5.80	3.08	.133	-2.76	14.36
3	2	3.13	3.43	.413	-6.39	12.66
3	4	1.97	2.69	.505	-5.51	9.44
4	1	3.83	3.36	.318	-5.51	13.17
4	2	1.17	3.69	.767	-9.07	11.40
4	3	-1.97	2.69	.505	-9.44	5.51

Note. Based on observed means. The error term is Mean Square(Error) = 27.167. CI = confidence interval. Group codes: 1 = No / Not at all, 2 = Somewhat, 3 = Mostly, 4 = Completely. * The mean difference is significant at the .05 level.

Appendix D. *Effect of Administering Periodic Olympiad Exams on Teacher Content Knowledge (TCK) and Student Achievement (SA)*

(I) Group	(J) Group	Mean Difference (I-J)	*SE*	*Sig.*	95% CI Lower	95% CI Upper
Teacher Content Knowledge (TCK)						
1	3	-16.41	6.14	.056	-33.45	0.64
1	4	-34.79*	8.39	.014	-58.08	-11.51
3	1	16.41	6.14	.056	-0.64	33.45
3	4	-18.39	6.91	.056	-37.57	0.80
4	1	34.79*	8.39	.014	11.51	58.08
4	3	18.39	6.91	.056	-0.80	37.57
Student Achievement (SA)						
1	3	-5.06	2.91	.157	-13.15	3.03
1	4	-2.67	3.98	.540	-13.72	8.39
3	1	5.06	2.91	.157	-3.03	13.15
3	4	2.40	3.28	.506	-6.71	11.50
4	1	2.67	3.98	.540	-8.39	13.72

4	3	-2.40	3.28	.506	-11.50	6.71

Note. Based on observed means. The error term is Mean Square(Error) = 27.167. CI = confidence interval. Group codes: 1 = No / Not at all, 2 = Somewhat, 3 = Mostly, 4 = Completely. * The mean difference is significant at the .05 level.

Appendix E. *Effect of Olympiad Planning Activities on Teacher Content Knowledge (TCK) and Student Achievement (SA)*

(I) Group	(J) Group	Mean Difference (I-J)	*SE*	*Sig.*	95% CI Lower	95% CI Upper
Teacher Content Knowledge (TCK)						
1	2	-20.88*	7.37	.047	-41.33	-0.42
1	3	-20.63*	6.72	.037	-39.29	-1.96
1	4	-21.04*	7.09	.041	-40.72	-1.36
2	1	20.88*	7.37	.047	0.42	41.33
2	3	0.25	6.26	.970	-17.13	17.63
2	4	-0.17	6.65	.981	-18.63	18.29
3	1	20.63*	6.72	.037	1.96	39.29
3	2	-0.25	6.26	.970	-17.63	17.13
3	4	-0.42	5.93	.947	-16.88	16.05
4	1	21.04*	7.09	.041	1.36	40.72
4	2	0.17	6.65	.981	-18.29	18.63
4	3	0.42	5.93	.947	-16.05	16.88
Student Achievement (SA)						
1	2	-1.80	3.50	.634	-11.51	7.91
1	3	-0.88	3.19	.798	-9.74	7.99
1	4	-4.50	3.36	.252	-13.84	4.84
2	1	1.80	3.50	.634	-7.91	11.51
2	3	0.93	2.97	.771	-7.32	9.17
2	4	-2.70	3.16	.441	-11.46	6.06
3	1	0.88	3.19	.798	-7.99	9.74

3	2	-0.93	2.97	.771	-9.17	7.32
3	4	-3.63	2.81	.267	-11.44	4.19
4	1	4.50	3.36	.252	-4.84	13.84
4	2	2.70	3.16	.441	-6.06	11.46
4	3	3.63	2.81	.267	-4.19	11.44

Note. Based on observed means. The error term is Mean Square(Error) = 27.167. CI = confidence interval. Group codes: 1 = No / Not at all, 2 = Somewhat, 3 = Mostly, 4 = Completely. * The mean difference is significant at the .05 level.

Appendix F. *Effect of Organizing Extracurricular Olympiad Events on Teacher Content Knowledge (TCK) and Student Achievement (SA)*

(I) Group	**(J) Group**	**Mean Difference (I-J)**	***SE***	***Sig.***	**95% CI Lower**	**95% CI Upper**
Teacher Content Knowledge (TCK)						
1	2	-16.38	7.37	.090	-36.83	4.08
1	3	-1.32	6.60	.851	-19.64	17.00
1	4	-25.88*	7.37	.025	-46.33	-5.42
2	1	16.38	7.37	.090	-4.08	36.83
2	3	15.06	6.12	.070	-1.95	32.06
2	4	-9.50	6.94	.243	-28.78	9.78
3	1	1.32	6.60	.851	-17.00	19.64
3	2	-15.06	6.12	.070	-32.06	1.95
3	4	-24.56*	6.12	.016	-41.56	-7.55
4	1	25.88*	7.37	.025	5.42	46.33
4	2	9.50	6.94	.243	-9.78	28.78
4	3	24.56*	6.12	.016	7.55	41.56
Student Achievement (SA)						
1	2	-2.35	3.50	.538	-12.06	7.36
1	3	-2.97	3.13	.396	-11.67	5.72

1	4	0.25	3.50	.946	-9.46	9.96
2	1	2.35	3.50	.538	-7.36	12.06
2	3	-0.62	2.91	.841	-8.69	7.45
2	4	2.60	3.30	.474	-6.55	11.75
3	1	2.97	3.13	.396	-5.72	11.67
3	2	0.62	2.91	.841	-7.45	8.69
3	4	3.22	2.91	.330	-4.85	11.29
4	1	-0.25	3.50	.946	-9.96	9.46
4	2	-2.60	3.30	.474	-11.75	6.55
4	3	-3.22	2.91	.330	-11.29	4.85

Note. Based on observed means. The error term is Mean Square(Error) = 27.167. CI = confidence interval. Group codes: 1 = No / Not at all, 2 = Somewhat, 3 = Mostly, 4 = Completely. * The mean difference is significant at the .05 level.

Appendix G. *Effect of Using Olympiad Resources on Teacher Content Knowledge (TCK) and Student Achievement (SA)*

(I) Group	(J) Group	Mean Difference (I-J)	*SE*	*Sig.*	95% CI Lower	95% CI Upper
Teacher Content Knowledge (TCK)						
1	2	-13.50	6.94	.124	-32.78	5.78
1	3	-8.42	6.65	.274	-26.88	10.04
1	4	-10.50	6.43	.178	-28.35	7.35
2	1	13.50	6.94	.124	-5.78	32.78
2	3	5.08	6.65	.487	-13.38	23.54
2	4	3.00	6.43	.665	-14.85	20.85
3	1	8.42	6.65	.274	-10.04	26.88
3	2	-5.08	6.65	.487	-23.54	13.38
3	4	-2.08	6.11	.750	-19.04	14.88
4	1	10.50	6.43	.178	-7.35	28.35
4	2	-3.00	6.43	.665	-20.85	14.85

4	3	2.08	6.11	.750	-14.88	19.04
Student Achievement (SA)						
1	2	-9.40*	3.30	.046	-18.55	-0.25
1	3	2.53	3.16	.467	-6.23	11.30
1	4	-4.23	3.05	.238	-12.70	4.24
2	1	9.40*	3.30	.046	0.25	18.55
2	3	11.93*	3.16	.019	3.17	20.70
2	4	5.17	3.05	.165	-3.30	13.64
3	1	-2.53	3.16	.467	-11.30	6.23
3	2	-11.93*	3.16	.019	-20.70	-3.17
3	4	-6.76	2.90	.080	-14.81	1.29
4	1	4.23	3.05	.238	-4.24	12.70
4	2	-5.17	3.05	.165	-13.64	3.30
4	3	6.76	2.90	.080	-1.29	14.81

Note. Based on observed means. The error term is Mean Square(Error) = 27.167. CI = confidence interval. Group codes: 1 = No / Not at all, 2 = Somewhat, 3 = Mostly, 4 = Completely. * The mean difference is significant at the .05 level.

***Appendix H**. Multivariate Tests for OPA Subdomains on Teacher Content Knowledge (TCK) and Student Achievement (SA)*

Effect	Statistic	Value	*F*	Hypothesis df	Error df	*Sig.*
Intercept	Pillai's Trace	.995	301.699	2.000	3.000	.000
	Wilks' Lambda	.005	301.699	2.000	3.000	.000
	Hotelling's Trace	201.132	301.699	2.000	3.000	.000
	Roy's Largest Root	201.132	301.699	2.000	3.000	.000
Lesson Delivery	Pillai's Trace	.119	.203	2.000	3.000	.827

	Wilks' Lambda	.881	.203	2.000	3.000	.827
	Hotelling's Trace	.135	.203	2.000	3.000	.827
	Roy's Largest Root	.135	.203	2.000	3.000	.827
Olympiad Camp	Pillai's Trace	.038	.059	2.000	3.000	.943
	Wilks' Lambda	.962	.059	2.000	3.000	.943
	Hotelling's Trace	.040	.059	2.000	3.000	.943
	Roy's Largest Root	.040	.059	2.000	3.000	.943
Periodic Exam	Pillai's Trace	.000	—	—	—	—
	Wilks' Lambda	1.000	—	—	3.500	—
	Hotelling's Trace	.000	—	—	2.000	—
	Roy's Largest Root	.000	.000	2.000	2.000	1.000
Planning	Pillai's Trace	.753	1.209	4.000	8.000	.378
	Wilks' Lambda	.345	1.055	4.000	6.000	.453
	Hotelling's Trace	1.618	.809	4.000	4.000	.579
	Roy's Largest Root	1.417	2.834	2.000	4.000	.171
Extracurricular Events	Pillai's Trace	.000	—	—	—	—
	Wilks' Lambda	1.000	—	—	3.500	—

	Hotelling's Trace	.000	—	—	2.000	—
	Roy's Largest Root	.000	.000	2.000	2.000	1.000
Use of Resources	Pillai's Trace	1.023	2.095	4.000	8.000	.173
	Wilks' Lambda	.142	2.481	4.000	6.000	.154
	Hotelling's Trace	4.879	2.440	4.000	4.000	.204
	Roy's Largest Root	4.628	9.255	2.000	4.000	.032

Note. Design: Intercept + Lesson Delivery + Olympiad Camp + Periodic Exam + Planning + Extracurricular Events + Use of Resources. Dashes (—) indicate values not computable due to zero degrees of freedom.