education sciences

MDPI

Article

The Implementation of Cognitively Challenging Tasks: The Role of Science Teachers' Professional Development and Teaching Experience

Palmira Pečiuliauskienė * and Lina Kaminskienė

Education Academy, Vytautas Magnus University, LT-44248 Kaunas, Lithuania; lina.kaminskiene@vdu.lt

* Correspondence: palmira.peciuliauskiene@vdu.lt

Abstract: This study deals with the implementation of cognitively challenging tasks for students in science education following professional development interventions for teachers based on the theory of change. These tasks require non-routine behaviors and encourage students to work beyond instructions and accept a high level of responsibility. This study explores how the content of professional development, the duration of professional development, and the extent of the teaching experience of science teachers are associated with the implementation of cognitively challenging science tasks in science education. A secondary data analysis of Trends in International Mathematics and Science Study (TIMSS) 2019 data from three countries (Singapore, Lithuania, and South Africa) was conducted. Ordinal logistic regression (OLR) was used to predict an ordinal dependent variable (the implementation of cognitively challenging science tasks) according to the independent variables (the content of professional development, the duration of professional development, and the extent of the teaching experience of science teachers). The results of the OLR confirmed that the implementation of cognitively challenging tasks is associated with professional development content (improving students' critical thinking or inquiry skills and science content) and the extent of the teaching experience of science teachers from the selected countries.

Keywords: cognitively challenging science tasks; professional development; science teacher; teaching experience

check for updates

Citation: Pečiuliauskienė, P.; Kaminskienė, L. The Implementation of Cognitively Challenging Tasks: The Role of Science Teachers' Professional Development and Teaching Experience. *Educ. Sci.* **2022**, *12*, 439. https://doi.org/10.3390/educsci12070439

Academic Editor: James Albright

Received: 6 June 2022
Accepted: 22 June 2022
Published: 24 June 2022

1. Introduction

Challenges are key factors in progress [1]. Future progress in science depends on the ability of the current generation of students to meet and overcome these challenges, an ability developed through cognitively challenging science tasks. These tasks require non-routine behaviors, demand that students to work beyond instructions, provide an individual with the freedom to determine how to accomplish tasks, and involve high levels of responsibility [2,3].

In schools, the ability of students to overcome challenges is determined by the capacity of science teachers to implement cognitively challenging tasks (ICCT) [4]. Improving the ability of science teachers to implement cognitively challenging science tasks is an extensive process that begins during their academic training years and continues through professional development (PD) [5]. PD is viewed as one of the most promising interventions for improving the quality of teaching [6–12].

The effectiveness of PD is a key factor in successful educational change, contributing to the higher achievements of students [13–16]. Typically, researchers question not the role of the efficacy of PD but the concept of PD's effectiveness itself, treating it separately [17,18]. Effectiveness can be understood in terms of the impact of teacher knowledge and teacher behavior on student results [17,18].

The theory of change (ToC) refers to the assumed relationship between the features of PD intervention and teacher knowledge and innovative work behavior [19–21]. This theory clarifies which indicators can be used to assess progress toward a long-term outcome and the preconditions en route to that outcome [22]. In seeking to refine the ToC, it seems reasonable to expect that the content focus of PD (intervention), the duration of PD (intervention), and the extent of teaching experience (intervention) will influence the outcomes—in other words, the implementation of cognitively challenging science tasks in science education. In this article, we describe a cognitively challenging science task approach to the PD and augmentation of the teaching experience of science teachers and explore how PD content, the duration of PD, and the extent of the teaching experience of science teachers are associated with the implementation of cognitively challenging science tasks in science education.

2. Establishment of Hypotheses

The PD of teachers is a long, multistage process. The conceptual model of PD presented by [17] explains the PD stages and effects as follows: PD intervention → increase in teacher knowledge → changes in teacher behavior → improvement in student results. This conceptual model highlights three aspects of PD: teacher knowledge, teacher behavior, and student results. Assuming that improved student results can be considered the only relevant indicator of successful PD, researchers should focus on the relationship between PD interventions and student results [23]. Presuming that a change in behavior is the result of changes in cognition, the focus should be on the relationships between PD intervention and cognition. If the assumption is that the results are due to teacher behavior or knowledge, the focus should be on the relationship between teacher behavior and PD interventions [18].

There is a long-held assumption that PD is key in supporting teacher change: "surprisingly little is known about the effectiveness of PD in changing teaching practice" [23] (p. 1219). Effective PD supporting changes among teachers leads to changes in teacher behavior [8,24–29] and culminates in improved student learning outcomes [29–33].

The long-held consensus model of effective PD helps elucidate the main insights regarding effective science teacher PD that encourages their innovative behavior [17,34]. Specifically, this model focuses on whether PD comprises specific subject matter content, the engagement of teachers in active learning, coherency in its alignment with teachers' learning experiences, a sufficient duration, a sufficient intensity, a certain number of contact hours, and a certain span of time over which the program occurs [17,34]. However, the long-held model provides only the general features of effective PD [23]. There is a lack of research analyzing the pathways between the general features of effective PD and the outcomes of science teachers' activity in education 1

Our study focuses on the relationship between effective PD interventions and the innovative work behaviors of science teachers, which stimulate the implementation of cognitively challenging tasks in the classroom. The ToC explains this focus by looking for effective interventions and preconditions of PD. Over the last few years, a substantial amount of research has focused on PD interventions, specifically their content, characteristics, and processes [13,35,36]. An analysis of the content aspect of this research indicated that previous researchers concentrated on constructivist approaches: inquiry, problem solving, learning cycles, thinking skills, and pedagogical and technological methods [26,37]. However, there is a lack of research on how a constructivist approach manifests itself in different educational activities in science education, especially when working on challenging science tasks.

The notion of challenging tasks refers to new activities that require non-routine abilities and allow an individual the freedom to determine how to accomplish tasks [2,3,8]. Students work on science tasks, defined as exercises or problems that focus their attention on different scientific ideas. Challenging tasks differ with respect to the level of cognitive activity, thinking, and reasoning required [4,33,38,39]. TIMSS 2011 data pertaining to eighth-grade students' science performance in Taiwan were analyzed, and it was revealed that the cognitive reasoning domain aspects of a task were more difficult for students than the applying and knowing domain aspects. Challenging tasks provide "a platform for trying a new behavior or reframing old ways of thinking or acting" [40] (p. 544). Solving challenging tasks requires abilities typical of innovative work behavior [8]. Considerable research has focused on the role played by teaching, teacher education, and PD in encouraging innovative behaviors in science teachers [28,30–33].

PD provides teachers with the science content knowledge, pedagogical content knowledge, and pedagogical skills needed for innovative science classroom activity. The authors of [23] provided causal evidence for the impact of a PD program on teachers' content knowledge, pedagogical content knowledge, and practice by exploring the relationships between these outcomes and student learning.

Summarizing the research on content-based PD interventions, the innovative work activities of science teachers, and the long-held consensus model of effective PD, the following hypothesis was established:

Hypothesis 1 (H1). *The implementation of cognitively challenging science tasks in science education is associated with the content-based PD of teachers.*

The long-held consensus model of effective PD specifies the importance of a sufficient duration, number of contact hours, and span of time over which the PD program occurs [19,39]. Effective PD facilitates changes in teachers' practice by providing them with adequate time to learn, exercise, implement, and reflect upon new practices [17,34]. PD initiatives for teachers typically take place in one-off workshops or over weeks, months, and even academic years [17,34]. Some research has indicated that PD activities require a sufficient duration, and that meaningful professional learning that translates to changes in practice cannot be accomplished in short, one-off workshops [13,17,41–43].

Researchers have argued that the duration of PD depends on the PD model [44,45]. Research on the duration of science teachers' PD has testified to the notion that a sustained duration has a positive effect on educational practices [45–47]. Heller et al. proposed three models of PD that incorporate the same science content learning but with different ways of examining teaching practices, including one that incorporates the analysis of students' work from cognitively challenging assessment tasks [44]. In Heller et al.'s study, certain ideas about science instruction were explained and discussed, while between the sessions teachers participated in related activities in their classrooms [44]. The findings of Heller et al. encourage investment in sustainable professional development that integrates content learning with the analysis of student learning and teaching [44].

Qualitative studies on sustained development have revealed that the duration of PD appears to be associated with a stronger impact on teachers and student learning, which is often supported by study groups and/or coaching [48]. A review of the literature on the PD of teachers demonstrated that there is a lack of quantitative evidence pertaining to the vital duration of PD and its concomitant impact on the implementation of cognitively challenging science tasks in science education and the collaborative, innovative activity of science teachers. As such, we hypothesized the following:

Hypothesis 2 (H2). *The implementation of cognitively challenging science tasks in science education is associated with the duration of PD for science teachers.*

The long-held consensus model of effective PD is coherent in its alignment with teachers' learning experiences [17,34]. The findings regarding the associations between teachers' professional experience and effective PD suggest that when teachers have a lot of experience with the subject content, they need little, if any, face-to-face PD support in the context of educative curriculum materials [45].

Scholars have analyzed the association between teachers' professional experience and innovative activities [35,49,50]. Other scholars have found that teachers' professional experience, teaching skills, and disposition influence educational practice [51]. In general, teachers gain professional experience in a process that begins with pre-service training and continues with in-service training [52]. Brekelmans et al. (2005) discussed the role of teacher experience in education and revealed two factors—specifically, time for acquiring the skills necessary to face challenges and enthusiasm for change and innovation—that implicate the usefulness of training [49]. Less experienced teachers may take a few years before they acquire these abilities, but teachers early in their careers have more enthusiasm to overcome challenges [49].

Hargreaves (2005) argued that experienced teachers are more relaxed and feel more comfortable engaging in their professional activities [25]. More experienced teachers, toward the end of their careers, become resistant to change [25]. Given this, it would be expected that teachers late in their careers would lose energy and would report less improvement than their younger colleagues. Hargreaves' (2005) findings suggest that less experienced teachers are more enthusiastic about change and initiate efforts in their own classrooms [50].

Ertesvåg's (2014) study investigated the effects of individual-level factors, such as the perceived classroom learning environment and work experience, and of school-level factors [35]. Moreover, work experience was found to have a positive effect, indicating that more experienced teachers reported a higher level of teaching quality than less experienced teachers. Thus, we hypothesized the following:

Hypothesis 3 (H3). *The implementation of cognitively challenging science tasks in science education is associated with science teachers' extent of teaching experience.*

3. Materials and Methods

3.1. Research Design

According to the ToC, measurement is an important factor in effective PD intervention [22]. We addressed the core research theme of our study using the Trends in International Mathematics and Science Study (TIMSS) 2019 database to measure the associations between the implementation of cognitively challenging science tasks; the teaching experience of science teachers; and PD interventions (the content of PD, the duration, and the span of time over which the PD occurs) (Figure 1). We performed a secondary data analysis of TIMSS 2019 data [53] with SPSS 23.

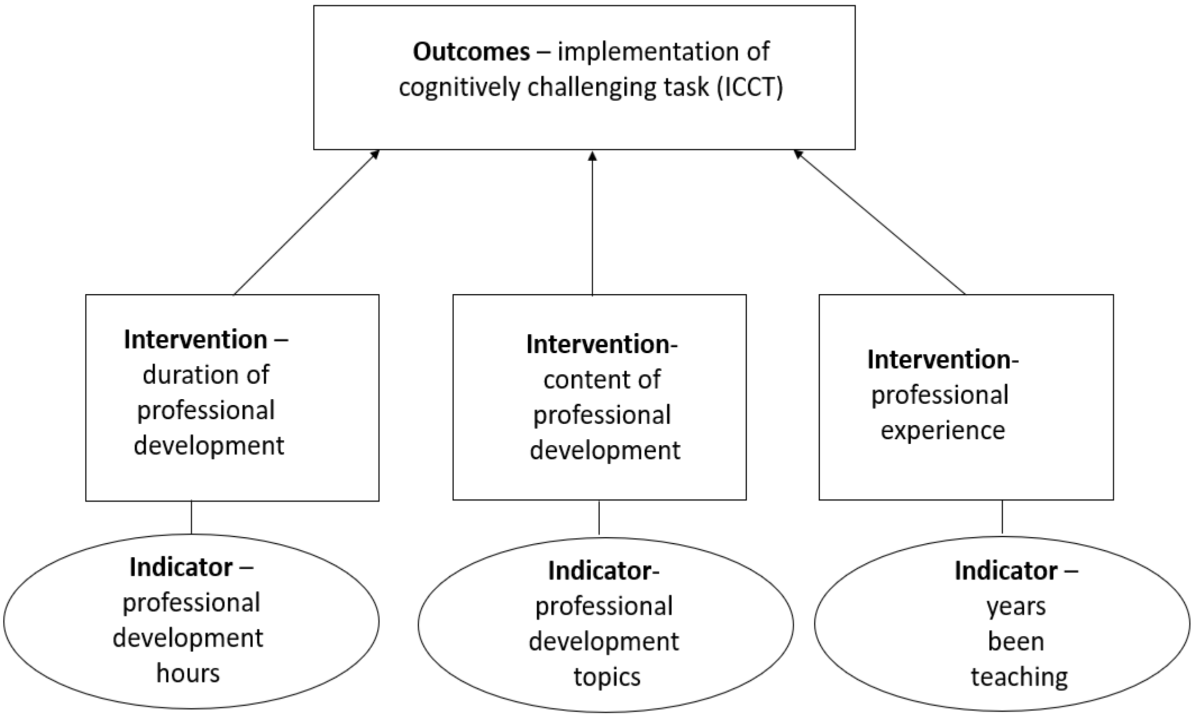

Figure 1. The interventions and outcomes of the implementation of cognitively challenging tasks.

The TIMSS 2019 instrument for science teachers supported the empirical analysis of the implementation of cognitively challenging science tasks, the assessment of the extent of teaching experience, and the assessment of PD interventions (content and duration). The TIMSS 2019 teacher questionnaire [54] included a question about the extent of teaching experience (BTBG 01: "By the end of this school year, how many years will you have been teaching altogether?"). The TIMSS 2019 survey asked teachers to provide an estimate of the cumulative hours of science PD they received in response to the question, "In the past two years, how many hours in total have you spent in formal in-service/professional development (e.g., workshops, seminars, etc.) for science?" (BTBS 22). The TIMSS 2019 survey also asked teachers to provide an estimate about PD program content (BTBS 21: "In the past two year, have you participated in professional development in any of the following?"). The following professional development topics were presented in the TIMSS 2019 questionnaire: (a) science learning (BTBS 21AA), (b) science pedagogy/instruction (BTBS 21AB), (c) science curriculum (BTBS 21AC), (d) integrating information technology in science (BTBS 21AD), (e) improving students' critical thinking or inquiry skills (BTBS 21AE), (f) science assessment (BTBS 21AF), and (g) addressing individual student needs (BTBS 21AG). TIMSS 2019 provides an opportunity to analyze the implementation of cognitively challenging science tasks (BTBG 12C) in science education: "How often do you do the following in teaching this class? Ask students to complete challenging exercises that require them to go beyond the instruction." The construct and internal validity of the TIMSS 2019 measurement scale are broadly supported by the TIMSS 2019 survey [54].

3.2. Sample

In this study, we conducted a secondary analysis of TIMSS 2019 data from three countries: Singapore, Lithuania, and South Africa. We selected the countries using the Average Science Achievement and Scale Score Distributions [54]. Specifically, we chose the two countries (Singapore and South Africa) with the most extreme positions according to Scale Score Distribution and one additional country (Lithuania) whose student science achievement is higher than the TIMSS 2019 survey average. Our study is based on ToC, and we did not aim to link the results of the study to student achievement.

3.3. OLR Model

Through the results of the study, we aim to highlight a method for generating a better understanding of the associations between the implementation of cognitively challenging science tasks and interventions, specifically the extent of science teachers' teaching experience, PD content, and PD duration (Figure 1). Ordinal logistic regression (OLR) was used to predict an ordinal dependent variable (the implementation of cognitively challenging science tasks) according to the independent variables (PD content, duration of PD, and teaching experience). The ordinal regression method Polytomous Universal Model (PLUM) was used to model the relationship between the above components.

We created the OLR model (1) to test the hypotheses based on the TIMSS 2019 data from three countries:

$$\text{ICCT} = \text{f (DPD, CPD, TE)} \quad (1)$$

where ICCT is the implementation of cognitively challenging tasks, DPD is the duration of teaching development (in hours), CPD is the content (topics) of professional development, and TE is the extent of teaching experience (according to the TIMSS 2019 question related to "years been teaching").

The OLR process involved checking four assumptions. The first assumption states that a dependent variable should be measured at the ordinal level. The dependent ordinal variable (ICCT), as a categorical variable, had four ordered categories: every or almost every lesson, about half of the lessons, some lessons, and never (Table 1).

Table 1. Percentage frequencies for the tested variable ICCT (implementation of cognitively challenging tasks): Singapore, Lithuania, and South Africa.

Country	Every or Almost Every Lesson	About Half of the Lessons	Some Lessons	Never
Singapore	6.6	42.5	48.1	2.8
Lithuania	9.8	33.2	53.7	3.3
South Africa	23.2	31.8	41.3	3.7

Applying percentage frequencies (Table 1), we observed that the variable ICCT displayed very small values for the category "Never", so it was more appropriate to use a categorical variable ICCT with fewer categories. We recoded the ranks "Some lessons" and "Never" into the variable "Some lessons and never".

After recording, the dependent variable ICCT remained with three categories: (1) every or almost every lesson, (2) about half of the lessons, and (3) some lessons and never. For the ordinal dependent variable ICCT with three categories, two (k − 1) equations were created, each with different intercepts but with the same b coefficients (slopes) for the predictor variables. This meant that the effects of the independent variables were the same for each level of the dependent variable. We tested this condition with the "test of parallel lines assumption".

The second assumption stated that one or more independent variables must be continuous, ordinal, or categorical (including dichotomous variables). However, ordinal independent variables must be treated as either continuous or categorical. We separated the independent variables (DPD, CPD, and TE) into covariates and factors. The continuous variable TE was assigned to covariates. We created a new categorical variable DPD with two categories, (1) short PD (up to 15 h) and (2) long PD (more than 16 h), based on the primary data (Table 2). The categorical variable DPD was assigned to the factors.

Table 2. The duration of the professional development of science teachers over the last two years in hours: Singapore, Lithuania, and South Africa.

Duration	Singapore	Lithuania	South Africa
None	0.9	5.4	9.6
Less than 6 h	7.5	9.2	25.1
6–15 h	33.0	35.5	27.9
16–35 h	25.5	30.9	17.7
More than 35 h	33.0	19.0	19.6

We treated independent variable CPD as categorical (dichotomous variable), and it was assigned to covariates. The variable CPD is complex, consisting of a variety of PD topics: science content, science pedagogy, science curriculum, integrating information and communication technology, improving students' critical thinking or inquiry skills, science assessment, and addressing individual student needs (Table 3).

Table 3. The percentage of science teachers participating in professional development teaching topics.

Teaching Topics	Question Code	Singapore	Lithuania	South Africa
Science content	BTBS 21AA	57.5	59.6	73.1
Science pedagogy	BTBS 21AB	87.7	46.8	49.3
Science curriculum	BTBS 21AC	66.0	41.8	72.1
Integrating information and communication technology	BTBS 21AD	65.1	56.9	44.4
Improving students' critical thinking or inquiry skills	BTBS 21AE	61.3	56.8	44.8
Science assessment	BTBS 21AF	71.7	53.4	60.5
Addressing individual students' needs	BTBS 21AG	44.3	54.1	40.5

The results of the descriptive statistics revealed the peculiarities of the PD topics (Table 3). Singaporean teachers were most often involved in PD regarding science pedagogy, science assessment, and science curriculum and were least involved in addressing individual student needs. The science teachers from Lithuania were most often involved in PD related to science content and integrating information and communication technology and were less involved in PD regarding the science curriculum. The teachers from South Africa most often participated in PD related to science content and science curriculum and less often in PD related to individual students' needs (Table 3).

We also examined the continuous variable "length of teaching experience" (TE). The mean and median of the years teaching of science teachers varied from country to country (Table 4). According to TIMSS 2019 data, the highest mean and median of the years teaching were in Lithuania and the lowest in Singapore (Table 4).

Table 4. Descriptive statistics of the length of teaching experience of science teachers.

Sample Size and Variables	Singapore	Lithuania	South Africa
Sample size	306	901	509
Years teaching (mean)	10.76	25.42	15.14
Years teaching (median)	8.00	26.00	14.00

4. Results

We begin our discussion of the OLR results with the test of the third assumption. We performed multiple linear regression to test the multicollinearity of the predictor variables (Table 5). The results of the multiple linear regression revealed that the independent variables (predictors) were not highly correlated with each other (VIF < 4). This led to the understanding that all the models' variables contribute to the explanation of the dependent variable.

Table 5. Collinearity statistics of predictors.

PD Intervention	Singapore		Lithuania		South Africa	
	Tolerance	VIF	Tolerance	VIF	Tolerance	VIF
BTBS 22	0.826	1.211	0.847	1.180	0.851	1.175
BTBS 21AA	0.823	1.215	0.758	1.320	0.523	1.911
BTBS 21AB	0.716	1.396	0.836	1.196	0.655	1.528
BTBS 21AC	0.762	1.312	0.786	1.272	0.491	2.038
BTBS 21AD	0.856	1.168	0.914	1.095	0.687	1.455
BTBS 21AE	0.702	1.425	0.903	1.107	0.606	1.650
BTBS 21AF	0.766	1.306	0.867	1.153	0.558	1.791
BTBS 21AG	0.781	1.280	0.879	1.137	0.677	1.478
BTBG 01	0.911	1.098	0.978	1.022	0.972	1.029

We compared the model without any explanatory variables (the baseline or intercept-only model) against the model with all the explanatory variables (the "Final" model; Table 6). The parameters of the model for which the model fit was calculated were predicted using the data of three different countries: Singapore, Lithuania, and South Africa (Table 6). The significant chi-square result ($p < 0.05$) indicated that the Final model demonstrated a significant improvement over the baseline or intercept-only model. The small p-value from the model fit test, <0.05, allowed us to conclude that at least one of the regression coefficients in the model was not equal to zero.

Table 6. Model fitting information.

Country	Model	−2 Log Likelihood	Chi-Square	df	p
Singapore	Intercept-only	181.065			
	Final	151.571	29.494	9	0.001
Lithuania	Intercept-only	1527.855			
	Final	1458.945	68.910	9	0.000
South Africa	Intercept-only	971.658			
	Final	937.753	33.905	9	0.000

Link function: Logit.

We checked whether our ordinal regression model (1) had overall goodness of fit. The Pearson's chi-square result confirmed that the observed data were consistent with the fitted model: for data from Singapore, χ^2 (179) = 0.932 > 0.05; Lithuania, χ^2 (1465) = 0.620 > 0.05; and South Africa, χ^2 (809) = 0.420 > 0.05). The pseudo-R squares (Nagelkerke) were used to assess the overall goodness of fit of our models: for Singapore, the sample R^2= 0.293; Lithuania, R^2 = 0.208; and South Africa, R^2 = 0.174.

Cumulative odds OLR with proportional odds was run to determine how the extent of teaching experience, the duration of PD, and the content of professional development predict the frequency with which science teachers from Singapore, Lithuania, and South Africa implement cognitively challenging tasks. The fourth assumption of proportional odds was assessed by a full likelihood-ratio test (test of parallel lines) to compare the fit of the proportional odds model to the model with varying location parameters. The test of parallel lines compares the ordinal model that has one set of coefficients for all thresholds (null hypothesis) to a model with a separate set of coefficients for each threshold (general). We were led to reject the assumption of proportional odds if the general model demonstrated a significantly better fit to the data than the ordinal (proportional odds) model ($p < 0.05$). The results of the test of parallel lines confirmed the null hypothesis that the ICCT model had one set of coefficients based on the data from Singapore, Lithuania, and South Africa (Table 7). The assumption was met in the Lithuanian sample (χ^2[9] = 13.208, p = 0.153), in the Singaporean sample (χ^2[9] = 13.649, p = 0.135), and in the South African sample (χ^2[9] = 8.495, p = 0.485).

Table 7. Test of parallel lines to explain the collaborative innovative activity of science teachers, using the data from Singapore.

Country	Model	−2 Log Likelihood	Chi-Square	df	p
Singapore	Null hypothesis	151.571			
	General	137.921	13.649	9	0.135
Lithuania	Null hypothesis	1458.945			
	General	1445.737	13.208	9	0.153
South Africa	Null hypothesis	937.753			
	General	929.259	8.495	9	0.485

Link function: Logit.

4.1. Wald's Statistics for the Data from Lithuania

Let us estimate the coefficients of the ordinal regression model based on the Wald's statistics for the data from Lithuania (Table 8).

Table 8. Parameter estimates to explain the implementation of cognitively challenging science tasks (ICCT model), using the data from Lithuania.

Predictor	B	SEB	Wald χ^2	p	OR	95% CI OR Lower	95% CI OR Upper
(TE) Teaching experience	0.037	0.0065	33.146	0.000	1.038	1.025	1.051
(CPD) Science content	0.644	0.1605	16.103	0.000	1.904	1.390	2.607
(CPD) Science pedagogy	−0.056	0.1465	0.146	0.703	0.946	0.710	1.260
(CPD) Science curriculum	0.122	0.1523	0.642	0.423	1.130	0.838	1.523
(CPD) Integrating ICT	0.007	0.1415	0.002	0.961	1.007	0.763	1.329
(CPD) Critical thinking	0.428	0.1431	8.965	0.003	1.535	1.159	2.031
(CPD) Science assessment	0.282	0.1453	3.777	0.052	1.326	0.998	1.763
(CPD) Students' needs	−0.037	0.1432	0.068	0.794	0.963	0.728	1.275
(DPD = 1.00) Short PD	−0.360	0.1454	6.137	0.013	0.698	0.525	0.928
(DPD = 2.00) Long PD	0 a				1		

Note: B = unstandardized coefficient; SEB = standard error for unstandardized beta; Wald χ^2 = Wald chi-squared test; p = probability level; OR = odds ratio; 95% CI OR = Wald confidence interval for odds ratio; TE = extent of teaching experience; CPD = content (topics) of professional development; DPD = duration of teaching development (in hours); a = set to zero because this parameter is redundant.

The results of the OLR for the Lithuanian data revealed that the predictor of teaching experience had a statistically significant value (Table 8).

The predictor variable TE (scale) in the OLR contributed to the model. The ordered log odds (estimate) = 0.037, SE = 0.0065, Wald $\chi^2(1)$ = 33.146, and $p < 0.05$. The estimated odds ratio (OR) favored a positive relationship of nearly 1.038 fold (Exp (estimate) = 1.038, 95% confidence interval (CI) = [1.025, 1.051]) for every unit increase in TE (scale). This means that the possibility of implementing cognitively challenging tasks increased 1.038 times for every unit increase in TE (scale).

The coefficient of the predictor DPD had a negative sign (Table 8), indicating that the predictor DPD (DPD = 1 means that the duration of PD was less than 15 h) has a negative effect on the implementation of cognitively challenging science tasks. The ordered log odds (estimate) = −0.360, SE = 0.1445, Wald $\chi^2(1)$ = 6.137, and $p < 0.05$. The estimated ORs favored a negative relationship of nearly 0.698 fold (Exp (estimate) = 0.698, 95% CI = [0.525, 0.928]) for every unit increase in DPD (scale).

For the predictor CPD Wald, the coefficient had a statistical value twice that of science content and the improvement of students' critical thinking or inquiry skills (Table 8). The predictor variable CPD (science content) in the OLR was found to contribute to the ICCT model. The ordered log odds (estimate) = 0.644, SE = 0.1605, Wald $\chi^2(1)$ = 16.103, and $p < 0.05$. The estimated OR favored a positive relationship of nearly 1.904 fold (Exp (estimate) = 1.904, 95% CI = [1.390, 2.607]) for every unit increase in CPD (science content) (Table 8).

The predictor variable CPD (critical thinking or inquiry skills) in the OLR was found to contribute less to the ICCT model compared to the predictor variable CPD (science content). The ordered log odds (estimate) = 0.428, SE = 0.1431, Wald $\chi^2(1)$ = 8.968, and $p < 0.05$. The estimated OR favored a positive relationship of nearly 1.904 fold (Exp (estimate) = 1.535, 95% CI = [1.159, 2.031]) for every unit increase in CPD (critical thinking or inquiry skills) (Table 8).

4.2. Wald's Statistics for the Data from South Africa

We performed ordinal logistic regression based on the Wald's statistics for the data from South Africa (Table 9). These results revealed that the predictor of the extent of science teachers' teaching experience (TE) had a statistically significant value and contributed to the model (Table 9).

Table 9. Parameter estimates to explain the implementation of cognitively challenging science tasks (ICCT model), using the data from South Africa.

Predictor	B	SEB	Wald χ^2	p	OR	95% CI OR Lower	Upper
(TE) Teaching experience	0.019	0.0082	5.117	0.024	1.019	1.002	1.035
(CPD) Science content	−0.414	0.2606	2.527	0.112	0.661	0.396	1.101
(CPD) Science pedagogy	−0.138	0.2047	0.452	0.501	0.871	0.583	1.302
(CPD) Science curriculum	0.153	0.2741	0.311	0.577	1.165	0.681	1.994
(CPD) Integrating ICT	0.060	0.2026	0.088	0.767	1.062	0.714	1.580
(CPD) Critical thinking	0.670	0.2123	9.955	0.002	1.954	1.289	2.963
(CPD) Science assessment	0.250	0.2336	1.144	0.285	1.284	0.812	2.030
(CPD) Students' needs	0.183	0.2017	0.824	0.364	1.201	0.809	1.783
(DPD = 1.00) Short PD	0.247	0.1862	1.759	0.185	1.280	0.889	1.844
(DPD = 2.00) Long PD	0 a				1		

Note: B = unstandardized coefficient; SEB = standard error for unstandardized beta; Wald χ^2 = Wald chi-squared test; p = probability level; OR = odds ratio; 95% CI OR = Wald confidence interval for odds ratio; TE = extent of teaching experience; CPD = content (topics) of professional development; DPD = duration of teaching development (in hours); a = set to zero because this parameter is redundant.

The ordered log odds (estimate) = 0.019, SE = 0.0082, Wald $\chi^2(1) = 5.117$, and $p < 0.05$. The estimated OR favored a positive relationship of nearly 1.019 fold (Exp (estimate) = 1.019, 95% CI [1.002, 1.035]) for every unit increase in TE (scale).

The predictor CPD Wald coefficient had a statistically significant value only once, for the improvement of students' critical thinking or inquiry skills (BTBS 21AE). The predictor variable CPD (critical thinking or inquiry skills) in the OLR was found to contribute to the ICCT model. The ordered log odds (estimate) = 0.670, SE = 0.2123, Wald $\chi^2(1) = 9.955$, and $p < 0.05$. The estimated OR favored a positive relationship of nearly 1.954 fold (Exp (estimate) = 1.954, 95% CI [1.289, 2.963]) for every unit increase in CPD (critical thinking or inquiry skills) (Table 9).

4.3. Wald's Statistics for the Data from Singapore and Summary of Wald's Statistics

We analyzed the data from Singapore to reveal the influence of different predictors (DPD, CPD, and TE) on the implementation of cognitively challenging tasks (Table 10).

Table 10. Parameter estimates to explain the implementation of cognitively challenging science tasks (ICCT model), using the data from Singapore.

Predictor	B	SEB	Wald χ^2	p	OR	95% CI OR Lower	Upper
(TE) Teaching experience	0.106	0.0299	12.575	0.000	0.899	0.848	0.954
(CPD) Science content	1.116	0.4755	5.514	0.019	3.054	1.203	7.755
(CPD) Science pedagogy	0.885	0.7663	1.333	0.248	2.423	0.539	10.880
(CPD) Science curriculum	−0.280	0.5026	0.311	0.577	0.756	0.282	2.024
(CPD) Integrating ICT	0.599	0.4816	1.547	0.214	1.820	0.708	4.678
(CPD) Critical thinking	1.088	0.5267	4.266	0.039	0.337	0.120	0.946
(CPD) Science assessment	0.910	0.5211	3.048	0.081	2.484	0.894	6.898
(CPD) Students' needs	0.049	0.4708	0.011	0.917	1.051	0.418	2.643
(DPD = 1.00) Short PD	−0.249	0.4524	0.302	0.582	0.780	0.321	1.893
(DPD = 2.00) Long PD	0 a				1		

Note: B = unstandardized coefficient; SEB = standard error for unstandardized beta; Wald χ^2 = Wald chi-squared test; p = probability level; OR = odds ratio; 95% CI OR = Wald confidence interval for odds ratio; TE = extent of teaching experience; CPD = content (topics) of professional development; DPD = duration of teaching development (in hours); a = set to zero because this parameter is redundant.

The predictor variable TE (scale) in the OLR was found to contribute positively to the ICCT model. The ordered log odds (estimate) = 0.106, SE = 0.0299, Wald $\chi^2(1) = 12.575$, and $p < 0.05$. The estimated OR favored a positive relationship of nearly 0.899 fold (Exp (estimate) = 0.899, 95% CI [.848, 0.954]) for every unit increase in TE (scale) (Table 10).

The predictor of the CPD Wald coefficient had a doubled statistically significant value for science content (BTBS 21AA) and for the improvement of students' critical thinking or inquiry skills (BTBS 21AE). The predictor variable CPD (science content) in the OLR was found to contribute to the ICCT model. The ordered log odds (estimate) = 1.116, SE = 0.4755, Wald $\chi^2(1) = 5.514$, and $p < 0.05$. The estimated OR favored a positive relationship of nearly 1.954 fold (Exp (estimate) = 3.054, 95% CI [1.203, 7.755]) for every unit increase in CPD (science content).

The predictor variable CPD (critical thinking or inquiry skills) in the OLR was found to contribute to the ICCT model. The ordered log odds (estimate) = 1.088, SE = 0.5267, Wald $\chi^2(1) = 4.266$, and $p < 0.05$. The estimated OR favored a positive relationship of nearly 0.337 fold (Exp (estimate) = 0.337, 95% CI [0.120, 0.946]) for every unit increase in CPD (critical thinking or inquiry skills) (Table 10).

Summarizing the results of the OLR for the data from Lithuania, South Africa, and Singapore, the confirmation of the hypotheses varied between the TIMSS 2019 data of different countries (Table 11).

Table 11. Results of hypothesis testing: the estimated odds ratio of the ICCT model.

Country	H_1: Predictor (CPD)		H2: Predictor (DPD)	H3: Predictor (TE)
	Science Content	Improving Students' Critical Thinking or Inquiry Skills		
Lithuania	1.904	1.535	0.608	1.038
South Africa	Not confirmed	1.954	Not confirmed	1.019
Singapore	3.054	0.337	Not confirmed	0.899

Note: DPD = the duration of teaching development (in hours); TE = the length of teaching experience.

5. Discussion and Conclusions

To address the three research hypotheses, we investigated the extent to which the three predictors (DPD, the duration of PD (in hours); CPD, the content (topics) of professional development; and TE, the extent of teaching experience) are associated with the implementation of cognitively challenging tasks in science education. The differing results (Table 11) may have been caused by the varying extents of teaching experience (Table 4), the participation in PD involving various topics (Table 3), and the varying durations of PD (Table 2).

The results of the OLR confirmed that the implementation of cognitively challenging tasks is associated with PD content (improving students' critical thinking or inquiry skills) and the extent of the teaching experience of science teachers from Singapore, Lithuania, and South Africa. However, the OLR did not confirm statistically significant associations between the duration of PD experienced by science teachers and the implementation of cognitively challenging science tasks based on data from Singapore and South Africa (Table 11).

To address the first hypothesis, we analyzed the association between the PD topics and ICCT. We determined that PD addressing the improvement of students' critical thinking or inquiry skills was positively associated with ICCT in the data from Lithuania, Singapore, and South Africa (Table 11). The percentage frequencies of science teachers participating in seminars focusing on improving students' critical thinking or inquiry skills did not dominate (Table 3), but hypothesis H1 (BTBS 21AE) was confirmed based on the TIMSS 2019 data for all the countries included in this study. This result is in line with the results of other studies on the positive role of constructivist approaches (inquiry, problem solving, learning cycles, thinking skills, and pedagogical and technological methods) on the quality of science education [26,37]. Our research singles out the positive role of inquiry-based PD content in the implementation of cognitively challenging science tasks.

Our study results confirmed the role of PD topic (science content) (hypothesis H1 (BTBS 21AA)) in ICCT twice: based on data from both Lithuania and Singapore (Table 11). An interesting result was found by testing hypothesis H1 (BTBS 21AA) using the data from Singapore. The OR of predictor BTBS 21AA (science content) for ICCT was the highest for the Singaporean data (Table 11). However, the least experienced science teachers were those from Singapore (Table 4). It can be assumed that the participation of science teachers in PD related to science content promotes the implementation of cognitively challenging tasks by science teachers with less teaching experience.

Hypothesis H1 (BTBS 21AA), which refers to the influence of participation in science content teaching on ICCT, was not confirmed by the South African data (Table 9). However, the highest percentage of South African teachers attended science content PD (Table 3). This result encourages further inquiry into the role of the duration of PD.

Our quantitative research pertaining to PD content-based training ascertained that the participation of science teachers in PD focusing on science content is related to the implementation of cognitively challenging science tasks. This result is in line with a longitudinal qualitative study on teachers' professional learning, including content knowledge, collective participation, and duration [33].

The fact that some researchers believe that a sustained duration is an important feature of PD and that PD activities require sufficient duration suggests that there are no alternatives to the sustained duration of PD [17,41–43]. However, others have been frustrated by the fact that the research has not yet identified a clear threshold for the duration of effective PD models [13,41]. OLR creates an opportunity for the determination of clear thresholds regarding the research into PD based on the TIMSS 2019 data from different countries.

By testing the second hypothesis using the data of three countries (Singapore, Lithuania, and South Africa), we deduced that the duration of PD predicts the ICCT by science teachers only in the case of Lithuania (Table 8). The coefficient of the predictor DPD had a negative sign (Table 8), meaning that less than 15 h of PD had a negative effect on the implementation of cognitively challenging science tasks. The primary data related to the duration of PD indicated that the highest percentage of science teachers from Singapore participated in long-duration PD (more than 16 h; Table 2). The highest percentage of science teachers from South Africa participated in short-duration PD (less than 15 h; Table 2). However, based on the data from Singapore and South Africa, the second hypothesis (H2) was not confirmed (Table 11).

The results of our study that addressed the extent of science teachers' experience (TE) in relation to ICCT indicated that this variable is statistically significantly associated with ICCT (Table 11). The data and descriptive statistics pertaining to the extent of the teaching experience of science teachers revealed that the median TE differed between countries: 8 years for teachers from Singapore, 14 years for those from South Africa, and 26 years for the Lithuanians (Table 4). Kaya and Gödek (2016) and Brekelmans et al. (2005) discussed the role of teachers' TE and suggested two factors: time for acquiring the skills to address challenges and enthusiasm about change [49,52]. On the one hand, our findings are in line with Hargreaves (2005), who stated that less experienced teachers are more enthusiastic about change initiatives in their own classrooms, whereby they believe they can best make a difference [50]. On the other hand, our findings are also in line with Ertesvåg (2014), who stated that more experienced teachers command a higher level of competency than less experienced teachers [35].

Limitations and Suggestions for Future Research

The limitations of our research should be kept in mind when interpreting the results of our hypothesis testing. OLR allowed us to analyze the effects of the different PD topics separately in light of the implementation of cognitively challenging science tasks by science teachers. It is possible to examine this notion with reference to a math model, but in a real situation, the influence of different PD content intervenes.

This limitation raises important and obvious practical and theoretical issues for science education researchers with respect to the impact of PD content and various complex outcomes.

The TIMSS teacher questionnaire measured the duration of PD without considering the form of PD realization. Based on the TIMSS data, teachers who reported the same total hours of PD could have achieved those hours by participating in many short-duration, disconnected activities (e.g., several-hour workshops on a variety of topics); participating in a single, longer-duration, and a coherent set of activities (e.g., multi-day program); or participating in a combination of activities of varying durations. For example, the duration of a one-day PD workshop can be accurately measured in hours, but the accurate estimation of the duration of sustained development is much more difficult because of the informal learning taking place within the classroom context between formal sessions. "By promoting learning over time, both within and between sessions, PD that is sustained may lead to many more hours of learning than is indicated by seat time alone" (Darling-Hammond et al., 2017, p. 16). However, the findings of our study encourage further research on the role of PD duration in the innovative activities of science teachers. It would be interesting to investigate whether the duration of PD is related to teachers' innovative activities when different PD forms are considered.

To obtain an acceptable model fit, we tested a mathematical model in which the duration of PD was transformed into two categories: (1) short PD (up to 15 h) and (2) long PD (more than 16 h). However, our study highlights the need to test alternative mathematical models using different categories for the duration of PD.

Author Contributions: Conceptualization, P.P. and L.K.; methodology, P.P.; software, P.P.; validation, P.P.; formal analysis, P.P. and L.K.; investigation, P.P. and L.K.; data curation, P.P.; writing—original draft preparation, P.P.; writing—review and editing, L.K.; visualization, P.P.; funding acquisition, L.K. All authors have read and agreed to the published version of the manuscript.

Funding: The open access was funded by the project "Comprehensive University Development in the Context of Universities Network Restructurisation", No 09.3.1-ESFA-V-738-02-0001.

Institutional Review Board Statement: In The research was carried out following the provisions which underline the basic principles of professionalism and ethics of research, approved by the Resolution No. SEN-N-17 of the Senate of Vytautas Magnus University of 24 March 2021. The study was conducted in accordance with the principles of reliability, integrity, respect, and accountability and with the provisions of point 23, which define the cases in which the investigator is required to submit to the evaluation committee his/her research plan for the validation of compliance with the professionalism and ethics of the research.

Informed Consent Statement: Not applicable. We performed a secondary analysis of TIMSS 2019 study data in accordance with the TIMSS 2019 ethical requirements for secondary data analysis.

Data Availability Statement: The datasets generated and analyzed during the current study are not publicly available due to privacy and ethical concerns but are available from the corresponding author on reasonable request.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Eberhart, J.; Hahn, S.; Seybel, C. Key factors and challenges of research-informed policy making in ECEC: Examples from longitudinal studies. *Int. J. Child Care Educ. Policy* **2017**, *11*, 1–17. [CrossRef]
2. Preenen, P.T.Y.; De Pater, I.E.; Van Vianen, A.E.M.; Keijzer, L. Managing voluntary turnover through challenging assignments. *Group Organ. Manag.* **2011**, *36*, 308–344. [CrossRef]
3. Preenen, P.T.Y.; Van Vianen, A.E.M.; De Pater, I.E. Challenging tasks: The role of employees and supervisors goal orientations. *Eur. J. Work Organ. Psychol.* **2014**, *23*, 48–61. [CrossRef]
4. Boston, M.D.; Smith, M.S. A 'task-centric approach' to professional development: Enhancing and sustaining mathematics teachers' ability to implement cognitively challenging mathematical tasks. *ZDM* **2011**, *43*, 965–977. [CrossRef]
5. Bada, S.; Prasadh, R.S. Professional Development of a Teacher for an Effective Teaching-Learning in School Education: A View. *J. Educ. Psychol.* **2019**, *13*, 7–13.

6. Bantwini, B.D. Developing a culture of collaboration and learning among natural science teachers as a continuous professional development approach in a province in South Africa. *Teach. Dev.* **2019**, *23*, 213–232. Available online: https://www.sciencegate.app/document/10.1080/13664530.2018.1533491 (accessed on 3 May 2021). [CrossRef]
7. Aziah, I.; Al Amin, M. The Impact of Transformational Leadership and Commitment on Teachers' Innovative Behaviour. In Proceedings of the 4th ASEAN Conference on Psychology, Counselling, and Humanities (ACPCH 2018), Surat Thani, Thailand, 9–10 November 2018; pp. 426–430.
8. Battistelli, A.; Odoardi, C.; Vandenberghe, C.; Di Napoli, G.; Piccione, L. Information sharing and innovative work behavior: The role of work-based learning, challenging tasks, and organizational commitment. *Hum. Resour. Dev. Q.* **2019**, *30*, 361–381. [CrossRef]
9. Campbell, C. Perspectives and Evidence on Effective CPD from Canada. In *Teacher CPD: International Trends, Opportunities and Challenges*; Shutt, C., Harrison, S., Eds.; Chartered College of Teaching: London, UK, 2019; pp. 68–74. Available online: https://chartered.college/international-teacher-cpd-report/ (accessed on 5 May 2021).
10. Chang, Y.C.H. Analyzing the moderating effect of knowledge innovation of tourism and hospitality department teachers on student creative self-efficacy and innovation behaviors by using hierarchical linear modeling. *Cogent Educ.* **2018**, *5*, 1–17. [CrossRef]
11. Klaeijsen, A.; Vermeulen, M.; Martens, R. Teachers' Innovative Behaviour: The Importance of Basic Psychological Need Satisfaction, Intrinsic Motivation, and Occupational Self-Efficacy. *Scand. J. Educ. Res.* **2018**, *62*, 769–782. [CrossRef]
12. Pudjiarti, E.S.; Hutomo, P.T.P. Innovative work behaviour: An integrative investigation of person-job fit, person-organization fit, and person-group fit. *Bus. Theory Pract.* **2020**, *21*, 39–47. [CrossRef]
13. Darling-Hammond, L.; Hyler, M.E.; Gardner, M. *Effective Teacher Professional Development*; Learning Policy Institute: Palo Alto, CA, USA, 2017.
14. Hargreaves, A. Teacher collaboration: 30 years of research on its nature, forms, limitations and effects. *Teach. Teach.* **2019**, *25*, 603–621. [CrossRef]
15. Karlberg, M.; Bezzina, C. The professional development needs of beginning and experienced teachers in four municipalities in Sweden. *Prof. Dev. Educ.* **2020**, 1–18. [CrossRef]
16. McMeeking, L.S.; Orsi, R.; Cobb, R.B. Effects of a teacher professional development program on the mathematics achievement of middle school students. *J. Res. Math. Educ.* **2012**, *43*, 159–181. [CrossRef]
17. Desimone, L.M. Improving impact studies of teachers' professional development: Toward better conceptualizations and measures. *Educ. Res.* **2009**, *38*, 181–199. [CrossRef]
18. Van Veen, K.; Zwart, R.C.; Meirink, J.F. What makes Teacher Professional Development Effective? A Literature Review. In *Teacher Learning That Matters: International Perspectives*; Kooy, M., Van Veen, K., Eds.; Routledge: New York, NY, USA, 2012.
19. Chen, H.T. *Theory-Driven Evaluations*; Sage: Thousand Oaks, CA, USA, 1990.
20. Coryn, C.L.S.; Noakes, L.A.; Westine, C.D.; Schröter, D.C. A systematic review of theory-driven evaluation practice from 1990 to 2009. *Am. J. Eval.* **2011**, *32*, 199–226. [CrossRef]
21. Weiss, C.H.; Connell, J.P. Nothing as Practical as Good Theory: Exploring Theory-Based Evaluation for Comprehensive Community Initiatives for Children and Families. In *New Approaches to Evaluating Community Initiatives: Concepts, Methods, and Contexts*; The Aspen Institute: Washington, DC, USA, 1995; pp. 65–92.
22. Reinholz, D.L.; Andrews, T.C. Change Theory and Theory of Change: What's the Difference Anyway? *Int. J. STEM Educ.* **2020**, *7*, 1–12. [CrossRef]
23. Roth, K.J.; Wilson, C.D.; Taylor, J.A.; Stuhlsatz, M.A.M.; Hvidsten, C. Comparing the Effects of Analysis-of-Practice and Content-Based Professional Development on Teacher and Student Outcomes in Science. *Am. Educ. Res. J.* **2019**, *56*, 1217–1253. [CrossRef]
24. Alshehry, A. Case Study of Science Teachers' Professional Development in Saudi Arabia: Challenges and Improvements. *Int. Educ. Stud.* **2018**, *11*, 70–76. [CrossRef]
25. Bilgin, A.; Balbag, M.Z. Personal professional development efforts of science and technology teachers in their fields. *J. Educ. Sci. Environ. Health JESEH* **2018**, *4*, 19–31. [CrossRef]
26. Chai, C.S. Teacher Professional Development for Science, Technology, Engineering and Mathematics (STEM) Education: A Review from the Perspectives of Technological Pedagogical Content (TPACK). *Asia Pac. Educ. Res.* **2018**, *28*, 5–13. [CrossRef]
27. Cervetti, G.N.; Kulikowich, J.M.; Bravo, M.A. The effects of educative curriculum materials on teachers' Use of instructional strategies for English language learners in science and on student learning. *Contemp. Educ. Psychol.* **2015**, *40*, 86–98. [CrossRef]
28. Chaudhuri, A.R.; McCormick, B.D.; Lewis, R., Jr. Standards-Based Science Institutes: Effective Professional Development That Meets Teacher and District Needs. *Sci. Educ.* **2019**, *27*, 15–23.
29. Shernoff, D.J.; Sinha, S.; Bressler, D.M.; Ginsburg, L. Assessing Teacher Education and Professional Development Needs for the Implementation of Integrated Approaches to STEM Education. *Int. J. STEM Educ.* **2017**, *4*, 13. [CrossRef]
30. EL-Deghaidy, H.; Mansour, N.; Aldahmash, A.; Alshamrani, S. A Framework for Designing Effective Professional Development: Science Teachers' Perspectives in a Context of Reform. *EURASIA J. Math. Sci. Technol. Educ.* **2015**, *11*, 1579–1601. [CrossRef]
31. Lownsbrough, S. Exploring approaches to ensure more effective professional development for English teachers. *RaPAL J.* **2020**, *101*, 30–37.
32. Sims, S.; Fletcher-Wood, H. Identifying the characteristics of effective teacher professional development: A critical review. *Sch. Eff. Sch. Improv.* **2021**, *32*, 47–63. [CrossRef]

33. Smith, R.; Ralston, N.C.; Naegele, Z.; Waggoner, J. Team Teaching and Learning: A Model of Effective Professional Development for Teachers. *Prof. Educ.* **2020**, *43*, 80–90.
34. National Academies of Sciences, Engineering, and Medicine (NASEM). *Science Teachers' Learning: Enhancing Opportunities, Creating Supportive Contexts*; National Academies Press: Washington, DC, USA, 2015.
35. Ertesvåg, S. Teachers' collaborative activity in school-wide interventions. *Soc. Psychol. Educ.* **2014**, *17*, 565–588. [CrossRef]
36. Moore, N.; Coldwell, M.; Perry, E. Exploring the role of curriculum materials in teacher professional development. *Prof. Dev. Educ.* **2021**, *47*, 331–347. [CrossRef]
37. Aldahmash, A.H.; Alshamrani, S.M.; Alshaya, F.S.; Alsarrani, N.A. Research Trends in In-Service Science Teacher Professional Development from 2012 to 2016. *Int. J. Instr.* **2019**, *12*, 163–178. [CrossRef]
38. Liou, P.-Y.; Bulut, O. The Effects of Item Format and Cognitive Domain on Students' Science Performance in TIMSS 2011. *Res. Sci. Educ.* **2020**, *50*, 99–121. [CrossRef]
39. Stein, M.K.; Lane, S. Instructional tasks and the development of student capacity to think and reason: An analysis of the relationship between teaching and learning in a reform mathematics project. *Educ. Res. Eval.* **1996**, *2*, 50–80. [CrossRef]
40. McCauley, C.D.; Ruderman, M.N.; Ohlott, P.J.; Morrow, J.E. Assessing the developmental components of managerial jobs. *J. Appl. Psychol.* **1994**, *79*, 544–560. [CrossRef]
41. Darling-Hammond, L.; Wei, R.C.; Andree, A.; Richardson, N.; Orphanos, S. *Professional Learning in the Learning Profession*; National Staff Development Council: Washington, DC, USA, 2009.
42. Knapp, M.S. Professional development as policy pathway. *Rev. Res. Educ.* **2003**, *27*, 109–157. [CrossRef]
43. Weiss, I.R.; Pasley, J.D. *Scaling Up Instructional Improvement through Teacher Professional Development: Insights from the Local Systemic Change Initiative*; Consortium for Policy Research in Education (CPRE) Policy Briefs: Philadelphia, PA, USA, 2006.
44. Heller, J.; Daehler, K.R.; Wong, N.; Mayumi, S. Differential effects of three professional development models on teacher knowledge and student achievement in elementary science. *J. Res. Sci. Teach.* **2012**, *49*, 333–362. [CrossRef]
45. Schuchardt, A.M.; Tekkumru, K.M.; Schunn, C.D.; Stein, M.K.; Reynolds, B. How much professional development is needed with educative curriculum materials? It depends upon the intended student learning outcomes. *Sci. Educ.* **2017**, *101*, 1015–1033. [CrossRef]
46. Penuel, W.R.; Gallagher, L.P.; Moorthy, S. Preparing teachers to design sequences of instruction in Earth systems science: A Comparison of three professional development programs. *Am. Educ. Res. J.* **2011**, *48*, 996–1025. [CrossRef]
47. Wenglinsky, H. *How Teaching Matters: Bringing the Classroom Back into Discussions of Teacher Quality*; Educational Testing Service: Princeton, NJ, USA, 2000.
48. Goodnough, K. Professional Learning of K-6 Teachers in Science Through Collaborative Action Research: An Activity Theory Analysis. *J. Sci. Teach. Educ.* **2016**, *27*, 747–767. [CrossRef]
49. Brekelmans, M.; Wubbels, T.; van Tartwijk, J. Teacher–student relationships across the teaching career. *Int. J. Educ. Res.* **2005**, *43*, 55–71. [CrossRef]
50. Hargreaves, A. Educational change takes ages: Life, career and generational factors in teachers' emotional responses to educational change. *Teach. Teach. Educ.* **2005**, *21*, 967–983. [CrossRef]
51. Kaya, V.H.; Elster, D. Environmental Science, Technology, Engineering, and Mathematics Pedagogical Content Knowledge: Teachers' Professional Development as Environmental Science, Technology, Engineering, and Mathematics Literate Individuals in the Light of Experts' Opinions. *Sci. Educ. Int.* **2019**, *30*, 11–20. [CrossRef]
52. Kaya, V.H.; Gödek, Y. Perspectives in regard to factors affecting the professional development of science teachers. *J. Hum. Sci.* **2016**, *13*, 2625–2640. [CrossRef]
53. Fishbein, B.; Foy, P.; Yin, L. TIMSS 2019 User Guide for the International Database. Retrieved from Boston College, TIMSS & PIRLS International Study Center. 2021. Available online: https://timssandpirls.bc.edu/timss2019/international-database/ (accessed on 15 April 2021).
54. Mullis, S., IV; Martin, M.O.; Foy, P.; Kelly, D.L.; Fishbein, B. TIMSS 2019 International Results in Mathematics and Science. Retrieved from Boston College, TIMSS & PIRLS International Study Center. 2020. Available online: https://timssandpirls.bc.edu/timss2019/international-results (accessed on 15 April 2021).