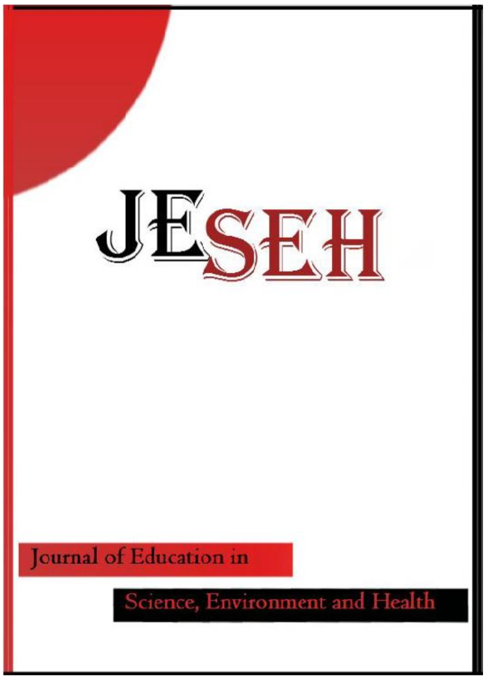

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Abstract

The purpose of the study is to examine the effects of a long-term professional development (PD) program on the classroom practices of physics teachers. Changes in teachers' practices were investigated across four dimensions: content, teaching strategy, materials/technology, and assessment. The present study used qualitative research methodology, including a case study research. Data were collected from seven participating teachers and their 9th grade students. The PD model framework has four main components: analysis, planning, implementation, and evaluation. A teacher survey, an observation form, a student group-interview protocol, treatment-fidelity and treatment-verification opinion forms were developed as measuring instruments. Thematic coding was used in every dimension. The data were evaluated using a frequency analysis and displayed in tables. The results showed that the PD program had a positive effect on teachers' classroom practices. The more the teachers participated in each dimension of the PD program, the greater the level of positive change observed in the teachers' lesson applications. When the results were examined in relation to teaching strategies, materials/technologies, and assessment techniques used for various purposes, there was a clear increase in the number, variety, and quality of strategies, materials, and technologies used in these dimensions.

Introduction

Teachers constitute a core component of education. They play a key role in preparing students for life and helping them become capable adults. They are responsible for implementing the school curriculum and control the creation of effective student-learning environments through the use of suitable teaching strategies, technologies, materials and assessment techniques that improve content understanding.

As teachers must be lifelong learners, professional development (PD) is a strong mechanism for improving their skills and advancing their careers. In addition, they must be qualified in terms of both content and pedagogical knowledge. To improve education, special attention should be paid to the quality of teachers. Some PD studies have asserted that PD is a crucial way of positively changing and improving teachers' classroom practices (Heller et al., 2012; Smith, 2015).

In general terms, the PD process increases a person's capacity to develop new knowledge and skills. It supports participants in a long-term and continuous way (Holmes et al., 2011). In the current context, PD is particularly important for science teachers because it enables them to apply learner-centered instruction effectively. This type of instruction focuses on what learners should know and do in the learning environment.

The literature identifies some important characteristics of effective PD programs. The common core features of PD proposed by Desimone et al. (2002), namely, content-based features, coherence, duration, active learning, and collective participation, have been confirmed by other studies (Darling-Hammond & Richardson, 2009; Desimone & Garet, 2015; Luft & Hewson, 2014; Penuel et al., 2007).

The scope of this research includes effective PD models, their characteristics, and possible outcomes in terms of teacher practices. Although there is a consensus that PD programs share some key characteristics, few studies have attempted to show how these characteristics are combined or how they affect teachers' practices, using long-term, systematic data collection procedures. Most research has been carried out during traditional short-term opportunities, such as seminars or workshops, which are not effective in enhancing the development of teachers (Clarke & Hollingsworth, 2002). The literature includes scant research on content-specific PD programs or pedagogical approaches in specific disciplines. There is clearly a need for more research to examine the changes made in real classroom situations by teachers who have participated in PD programs (Eylon et al. 2008; Wiener et al., 2018).

The Significance of the Present Study

Teachers are expected to develop effective classroom practices within the scope of this study. This model identifies the needs of teachers before the PD program is carried out. During the PD, teachers expand their content knowledge, use of materials/technologies, teaching strategies, and assessment techniques. One drawback is the duration (timespan) and contact time of PD programs. We have designed a long-term sustained program to ensure that teachers are aware of what is happening and have enough time to prepare their lessons. More research is needed on teachers' experiences to indicate PD research quality. Very few studies have followed the practice of teachers who have just participated in PD programs (Jackson, 2014). The present research combines qualitative designs with multiple data collection techniques. Manzaro and Toth (2013) have argued that data related to teaching practices should come from different sources. This study has therefore a range of different data-collection tools, including a needs-based survey, an observation form and interview protocol.

The present study discovers and explores actual classroom practices before and after the PD program. Goe (2007)'s broad definition states that practice refers to teachers' actions in the classroom with their students. Practice must be observable in class; it can be different in specific disciplines. The in-service classroom practices of physics teachers were assessed using systematic observation data prior to the PD program and again during the following fall term, after the PD program. Group interviews with students were also used to provide evidence of the teachers' behavioral changes in their classrooms. An effective PD model framework was developed, incorporating teachers who worked together on a voluntary basis in both face-to-face settings (workshops) and non-face-to-face interactions. This model incorporates effective 12 core PD characteristics into a single research design and investigates teacher practices before and after the PD program.

Main Question: What is the effect of the PD program on the in-service classroom practices of physics teachers?

SubQ1: To what extent are common topics emphasized by in-service physics teachers in physics classes before and after the PD program?

SubQ2: What and how frequently and effectively are teaching strategies used by in-service physics teachers in physics classes before and after the PD program?

SubQ3: What and how frequently and effectively are instructional materials/technologies used by in-service physics teachers in physics classes before and after the PD program?

SubQ4: What, for what purpose, and how frequently and effectively are assessment techniques used by in-service physics teachers in physics classes before and after the PD program?

Method

Research Methodology

The present study employed qualitative approaches and multiple data-collection methods. This study included case-study research methodology. The case study involved a systematic process of searching for and collecting events, and analyzing data to explain why particular events happened (Gerring, 2005). The entire group of teachers who participated in the PD program is treated as a single case in this study.

Participating Teachers

Seven teachers, referred to as TA, TB, TC, TD, TE, TF and TG for the sake of research convenience, participated in this study. Table 1 presents their demographic details and professional experiences, drawn from the TSNOP survey.

Table 1. Teachers' demographics and their professional experiences

Teachers	[1]Gender	Faculty graduated	Degree	Years of teaching	Type of school	[2]Previous PD experiences
TA	F	Education	MSc	18	Sport	• 4 times, 15 days, related to curriculum knowledge, passive participation • 4 times, 25 days, related to curriculum knowledge, active participation
TB	F	Education	BS	26	Anatolian	• 4 times, 4 days, related to curriculum knowledge, assessment, passive participation • 1 times, 15 days, related to basic computer, active participation
TC	M	Education	BS	24	Anatolian	• 1 times, 20 days, related to basic computer, active participation
TD	F	Education	MSc student	19	Vocational	• 2 times, 18 days, related to curriculum knowledge, passive participation • 4 times, 28 days, related to curriculum knowledge, assessment, active participation
TE	F	Science	BS	23	Anatolian	• 1 times, 15 days, related to curriculum knowledge, passive participation • 5 times, 39 days, related to curriculum knowledge, material development, active participation
TF	F	Education	PhD	11	Vocational	• 2 times, 9 days, related to curriculum knowledge, passive participation
TG	F	Science	BS	24	Vocational	• 3 times, 129 days, related to curriculum knowledge, basic computer, passive participation

1= F: female, M: male
2= The total number and duration of trainings so far, PD content, and the role of participant, respectively in the previous PD experiences section.

Measuring Instruments

Survey of teachers in the NOP-unit PD program (TSNOP). The TSNOP survey has 10 pages, divided into four parts. The first part covers the participants' demographic information. The second part includes questions about the teachers' professional experiences. Teachers are also asked to propose possible solutions to problems. They answer more specific questions about how training can be organized (e.g., type, context, PD roles, timing, etc.) in the third part.

Observation Form (OF)

It consists of two main parts. Part I evaluates the way in which teachers deliver content, their teaching strategies, and materials/technology; their classrooms are assessed through the implementation of this unit. Changes in practice were assessed for variety, number, and quality, as a result of the PD program. Part II covered general course-related elements that could be observed (e.g., physical situations within the context).

Table 2. General and common topics

General topics	Common topics (specific topics)
Science of physics and its purpose	O1: What is physics? O2: The aim of science of physics (why I need to know physics?)
Application fields of physics and its relation with other disciplines	O3: Physics practice areas, sub-areas O4: Physics' relation with other disciplines (chemistry, biology, etc.)
The relationship between physics and technology	O5: The relationship between physics and technology
Role of observation in emergence and development of scientific knowledge	O6: Role of observation in emergence and development of scientific knowledge O7:Qualitative-quantitative observation relationship
The emergence and development of knowledge and scientific methods	O8: The emergence and development of knowledge and scientific methods (law, theory, imagination and creativity)
Role of experiment in emergence and development of scientific knowledge	O9: Role of experiment in emergence and development of scientific knowledge (differences between hypothesis, theory, law)
Role of mathematics in emergence and development of scientific knowledge	O10: Role of mathematics in emergence and development of scientific knowledge
The use of mathematics and modeling in physics	O11: The use of mathematics and modeling in physics
Measurement of some basic quantities in physics and use of error and unit system in measurement	O12:Measurement of some basic quantities in physics and unit system O13: Error in measurement and its sources
Describing units of some basic quantities in physics in SI unit system	O14: Describing units of some basic quantities in physics in SI unit system

Student Group-Interview Protocol (SGIP)

The interview protocol had two parts. The first involved the dimensions of the PD content and its implementation in classes of teachers; the second part consisted of general questions about attitudes toward the unit and ways of improving lessons.

Treatment Fidelity Expert Opinion Form (TFEOF)

To ascertain treatment fidelity, a form was developed and sent to experts (university members, PD professionals, and teacher-education researchers). A detailed explanation followed each PD characteristic. The experts were asked two questions with three potential responses (“yes,” “no” and “partially”). The questions were as follows: “Could the given title be a characteristic of the PD program?” And “Is the given characteristic, along with its explanation, integrated into the PD program?.”

Treatment Verification Opinion Form (TVOF)

The treatment fidelity opinion form was modified to create a treatment verification form for the PD program. Using a treatment-verification format, seven teachers and researchers verified the same PD characteristics after the PD program finished. They were asked, “Did you do the things that I wrote about in the ‘What I did’ section of the TVOF form?” One question had three optional responses (“yes,” “no” and “partially”), allowing participants to approve the characteristics on the form.

Qualitative Data Analysis

Frequencies were calculated and tables were created to display the data. To code the observation data more accurately, a coding-manual observation form was developed. Lists of major criteria were created, along with a set of rules for each dimension. To increase coding reliability, criteria were established for scoring the quality of the three dimensions (teaching strategy, materials/technology, and assessment). As a new curriculum was implemented developed during the second fall term, the NOP content was modified for use as ISOP unit content. A total of 60 and 64 classroom hours were observed during the NOP and ISOP units, respectively. The same coding-manual observation form was used for both terms, to compare common topics covered in both units. A common topic is a common objective, included in both physics curricula. Fifteen common topics were used to compare teacher changes caused by the PD program in four dimensions; they were labelled with the letter "O" in the study (see Table 2).

After coding the observation form during the first fall term, we randomly selected a sample piece of data from a teachers' class data and examined the same piece of data nearly a month later. We calculated the agreement rate between these two linked pieces of data and found a 97% agreement. We then compared the results of the two terms to reveal changes in practice. The interviews (SGIP) were tape-recorded and then transcribed, question by question. We prepared a coding scheme, sorting out categories and sub-categories. We used a thematic approach (Miles & Huberman, 1994) to analyze the coded transcripts.

Procedure

We explained teacher development in each of the five phases (see in Figure 1.)

Figure 1. Design process of the PD program

Phase 1 includes all preparations for the PD program. The TSNOP, SGIP, literature review, and first fall-term observations provided the main sources of meaningful data, used to structure and develop content for the PD program. Workshop I was held during Phase 2. This workshop had both theoretical and practical features. Teachers attended 20 hours of face-to-face training: five sessions of four hours each (every other afternoon on a regular basis) over the course of two weeks. At the end of Workshop I, the common parts of both units were shared by eight teachers for Workshop II. They were responsible for teaching content and the use of teaching strategies and materials/technology. The remaining three teachers wanted to prepare tests for formative, diagnostic, placement, and summative purposes.

Phase 3 involved remote or virtual (not face-to-face) interactions between the two workshops. Teachers prepared teaching presentations during the summer. They interacted with colleagues and researchers via social networks and phone calls. Shortly before the start of the school term, they were given an opportunity to participate in teaching practice in Workshop II. This phase lasted for approximately two months and the virtual/remote interactions had an ongoing structure.

In Phase 4, the teachers lectured in Workshop II as if they were in an actual class. Workshop II was divided into three sessions, which included practical applications. Each session lasted for four hours. The workshop was spread out across three consecutive days, with afternoon meetings. Participating in-service physics teachers designed one-hour lessons for the next semester. They integrated available materials with suitable teaching strategies and shared their teaching practices with colleagues.

The teachers prepared for their classes after receiving feedback from Workshop II in Phase 5. They communicated with each other and us through remote or virtual interactions before the start of classes. The feedback results were distributed to teachers individually. Having been asked to modify and finalize the last version of their products, they uploaded their presentations onto a social platform and shared them with others before classes began. The remote and virtual interactions lasted for the whole of that time. In the same way, one researcher made post-classroom observations during the ISOP unit. Students in the observed classes were interviewed. The research sequence was the same as the sequence during the first fall term. The teachers filled out a treatment-verification form to ensure PD treatment. The total contact time was 42 hours, consisting of 32 hours of face-to-face interactions and 10 hours of non-face-to-face interactions. Figure 2 presents the PD model framework, which shows the pathway of the program.

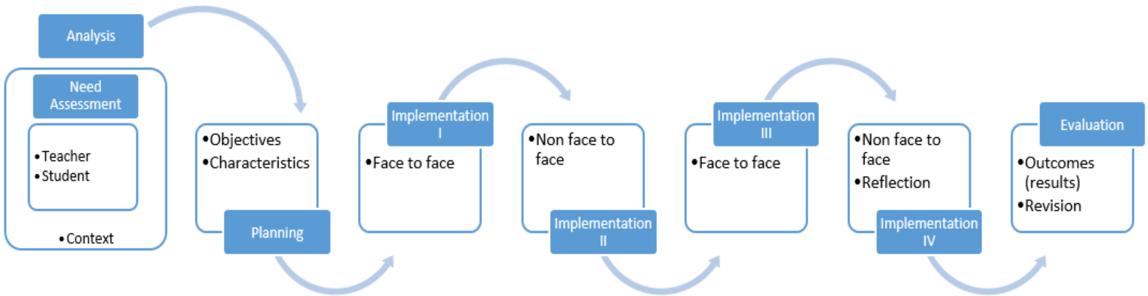

Figure 2. Professional development model framework

Results

Level of Teachers' Participation in the Professional Development Program

Table 3. Distribution rates of face-to-face and non-face-to-face interaction in the PD program

	Face-to-face interaction* (%)	Non-face-to-face interaction** (%)	Rate
Content	77	23	3
Teaching strategy	71	29	2
Material/technology	82	18	4
Assessment	90	10	9

*= [av. time for face-to-face / (av. time for face-to-face + av. time for non-face-to-face)] *100
**= [av. time for non-face-to-face / (av. time for face-to-face + av. time for non-face-to-face)] *100
(For instance; Average time passed in face-to-face interaction for content dimension is 8.7x60=522 minutes. This time is 160 minutes for non face-to-face interaction. Therefore, when calculating the percent of face-to-face interaction = [522/(522 + 160)]*100 formula was used and 77% was found).

Table 4. Core characteristics immersed in the PD program

	PD characteristics +: 1 point	Face-to-face interactions	None-face-to-face interactions
C1	Needs, demands		
1	Consider to the needs of teachers	+	+
2	Consider to the needs of students	+	+
C2	Awareness		
3	Convince teacher to change	+	+
C3	Support		
4	Support from MONE	+	+
5	Support from academicians/teachers a. Workshops, b. Materials/sources, c. Easy access to them	+++	+ (b.)
6	Support from schools a. Easy attendance to the program b. Easy implementation for researcher	++	++
C4	Motivation/incentive		
7	Giving a certificate as an incentive	+	+
8	Providing opportunity to see and compare the students' success related to the PD content	+	-
C5	Feedback		
9	Feedback from researcher	+	+
10	Feedback from teachers	+	+
11	Self-feedback	+	-
C6	Opportunity		
12	The opportunity to practice	+	-
C7	Planned and flexible program		
13	Planned and flexible program	+	+
14	Planned and flexible teacher application	+	-
C8	Duration		
15	Long term PD	+	+
16	Having an ongoing structure	+	+
17	Giving workshop nearly to the class implementation	+	+
C9	Content specific PD		
18	Getting to the core of ISOP unit	+	+
19	Aligning with the curriculum	+	+
C10	Active learning		
20	Effective/productive working	+	+
21	Reflective thinking/discussion	+	+
22	Mostly pursued by teacher	+	+
C11	Collaboration /Interaction		
23	a. Exchange of ideas, b. Group learning	++	+ (a.)
C12	Effective communication/Building learning community		
	Before workshop 1		
24*	Teacher to teacher communication	-	-
25	Teacher to instructor communication	+	+
	During workshop I		
26	Teacher to teacher communication	+	+
27	Teacher to instructor communication	+	+
	After workshop I / Before workshop II		
28	Teacher to teacher communication	+	+
29	Teacher to instructor communication	+	+
	During workshop II		
30	Teacher to teacher communication	+	+
31	Teacher to instructor communication	+	+
	After workshop II		
32	Teacher to teacher communication	-	+
33	Teacher to instructor communication	-	+

* The characteristics was unable to provide during the PD program.

The impact of the program on the practice of teachers was measured using the participation rate. A total of 32 hours of workshop time (Workshop I + Workshop II) was divided into four dimensions: 11 hours spent on content, 7 hours spent on teaching strategy, 7 hours spent on materials/technology, and 7 hours spent on assessment. We calculated the total participation time for each participant; as an example, TA participated during 9 out of 11 hours (82%). The average participation rates for face-to-face training in each dimension ranged between 77% and 80%. Non-face-to-face interactions (measured using the average results of seven teachers) were notable for their wide range, from a minimum of 35 minutes spent in the assessment dimension to a maximum of 160 minutes spent in the content dimension. Table 3 presents the percentage rates of training in each dimension, comparing face-to-face and remote/virtual interactions.

In the training sessions, the teachers discussed teaching strategy through face-to-face interactions as at least twice as often as through non-face-to-face interactions and nine times more often in the assessment dimension. According to the researchers' treatment-verification results, the ratio of face-to-face to non-face-to-face interactions was 1.2 (92/78); 33 items related to the 12 core PD characteristics (see Table 4.) were scored for this calculation.

Table 5. Teachers' weighted participation rate in each dimension

Content Dimension	Teacher	Face-to-face interaction (minute)	Face-to-face % (1)	Non-face-to-face interaction (minute)	Non-face- to-face % (2)	Total weighted participation rate
Content	TB	660	100	148	71	94
	TD	600	91	182	87	90
	TA	540	82	157	75	80
	TE	480	73	209	100	79
	TF	480	73	200	96	78
	TC	480	73	89	43	66
	TG	420	64	132	63	64
Teaching strategy	TB	420	100	142	82	95
	TD	360	86	173	100	90
	TE	360	86	125	72	82
	TF	300	71	168	97	79
	TG	360	86	96	55	77
	TA	240	57	168	97	69
	TC	240	57	80	46	54
Material/ technology	TB	420	100	87	75	96
	TD	360	86	94	81	85
	TF	360	86	56	48	79
	TA	300	71	116	100	76
	TG	360	86	28	24	75
	TE	300	71	64	55	69
	TC	240	57	78	67	59
Assessment	TB	420	100	22	35	94
	TD	360	86	46	73	85
	TF	360	86	7	11	79
	TA	300	71	63	100	74
	TE	300	71	52	83	72
	TG	300	71	8	13	66
	TC	240	57	47	75	59

(1) = (face-to-face interaction (min.) *100)/ interaction time (min.) in each dimension
(2) = (non-face-to-face interaction (min.) *100)/ max interaction (min.) in each dimension

Total weighted interaction rate formulas:
Content = (((1) *3.6+(2) *1))/(3.6+1)
Teaching strategy= (((1) *2.4+(2) *1))/(2.4+1)
Material/technology= (((1) *4.8+(2) *1))/(4.8+1)
Assessment= (((1) *10.8+(2) *1))/(10.8+1)

The face-to-face interaction section obtained a result of 34 out of 37 points (92%), whereas the non-face-to-face interaction section obtained a result of 29 (78%) points. Consequently, The PD program included 32 out of 33 characteristics (all except Characteristic 24). The 97% rate of agreement between teachers and researchers indicates that applied PD is a type of PD that is planned before the PD program. To understand the change of teacher practice in each dimension, based on the time teachers spent participating in the PD program, a weighted participation rate was calculated (see Table 5).

For example, the weighted participation rate of TB in the content dimension was calculated as follows: TB participated 100% in 660 minutes of face-to-face interaction lessons in Workshop I and Workshop II. As there is no upper limit for non-face-to-face interaction, the highest number of minutes reached by any teacher was accepted as the maximum. According to this, in comparison to TE, TB's percentage participation rate was approximately 71% of the maximum level of interaction ([148*100]/209), given a maximum of 209 minutes in this dimension. When calculating the total weighted participation rate, we used the formulas at the bottom of Table 4 for each dimension. Applying the content-dimension formula to TB produced the following result:

Content = (((1) *3.6+(2) *1))/(3.6+1)
(for (1), and (2) = see the explanations at the bottom of Table 4)
Content = ((100 *3.6+71*1))/(3.6+1) = 94 is obtained.

The 3.6 coefficient in this formula is achieved by multiplying the face-to-face interactions in each dimension by the non-face-to-face interaction rate (see at Table 3) and face-to-face interactions by the non-face-to-face interaction rate. This coefficient is calculated as 3 x 1.2 = 3.6 for content dimension.

The Results of the Teacher Practice Sessions

If participating teachers reached approximately 80% (the cut-off point) in the PD program weighted participation rates, we assumed that the program had affected them. The weighted participation rate for each teacher group classified those with 80% or more in the upper group and those with less than 80% in the lower group.

Findings of the SubQ1

TB, TD, TA, TE, TF were in the upper group, while TC and TG were in lower group, based on the weighted participation rates of each teacher in the program (Table 4). The change in the number of common topics before and after the PD program illustrates the difference between the two years of teacher practice sessions. As an example, TB completely delivered 7 common topics before the PD program and 15 common topics after the PD program.

When all of the teachers who participated in the PD program were considered, the number who delivered the full set of 15 common topics increased from an average of 4.4 to 10.3 (Table 6). This figure increased from 5.2 to 12.4 in the upper group of teachers, who obtained participation rates of 80% or above in the PD program. As can be seen from the table, the number of common topics they reached was quite close to 15. Some teachers (TB, TD) even delivered all of the common topics after the PD program. Consistently, alongside the increase in the number of common topics completely delivered, there was a decrease in the number of partially or wrongly delivered common topics among teachers in the upper group, after the program. None of the teachers failed to deliver any common topics after the PD program.

Most teachers completely delivered the common topics O1, O3, and O15 before the program. All teachers completely met the same target after the program. No teachers delivered the common topics O8, O9, or O12 before the PD program; this number slightly improved after the PD. As O8 and O9 contained misconceptions, these items increased; there were no other changes to the expected level. The common topic O12 included measuring some basic quantities and unit systems in physics. Some students described O12 as a difficult topic in the group interviews across both years.

Common topics other than O8, O9, O11, and O12 (and to some extent O10) were delivered completely by a quite a few teachers before the program. This number slightly increased after the program. There was some development on these common topics after the PD program. In addition, the total number of teachers who partially delivered O8, O9, O11, and O12 decreased by year, remaining the same as O10.

When we compare the number of partially delivered common topics with the number of completely delivered common topics, a positive change can be seen after the PD program. However, in all cases, scientific methods, hypotheses, theories, laws, and modelling concepts continued to cause trouble for teachers. When we consider the wrongly delivered common topics in the same way, the first items that catch our attention are O8 and O9. Errors decreased in O8 after the PD program; the same teacher (TC) continued to deliver O9 incorrectly. By contrast, O4 and O14, which were delivered incorrectly more often before the PD program, were delivered almost completely correctly after the PD program. In inter-class observations of teachers, O2 and O13 were taught by only one teacher before the program; strikingly, six teachers taught these subjects after the program.

Table 6. Common topics delivered for each teacher classified according to weighted participation

Common topics	Completely delivered		Partially delivered		Wrongly delivered		More delivered than aimed at the curriculum		None delivered		The common topics were stated		The common topics were associated with daily life	
Teacher	1	2	1	2	1	2	1	2	1	2	1	2	1	2
TB	7	15	5	0	3	0	3	0	0	0	4	14	5	7
TD	5	15	9	0	2	0	2	0	1	0	6	12	6	8
TA	6	12	9	2	2	1	3	0	0	0	7	13	5	9
TE	5	10	9	5	3	0	3	0	0	0	3	10	7	9
TF	3	10	8	4	5	2	2	0	2	0	0	13	3	7
Average	5.2	12.4	8.0	2.2	3.0	0.6	2.6	0.0	0.6	0.0	4.0	12.4	5.2	8.0
Difference	7.2		-5.6		-2.4		-2.6		-0.6		8.4		2.8	
TC	3	5	8	8	2	3	3	1	2	0	1	7	2	5
TG	2	5	7	10	3	0	2	0	3	0	0	9	4	5
Average	2.5	5.0	7.5	9.0	2.5	1.5	2.5	0.5	2.5	0.0	0.5	8.0	3.0	5.0
Difference	2.5		2.5		-1.0		-2.0		-2.5		7.5		2.0	
Total average	4.4	10.3	7.9	4.1	2.9	0.9	2.6	0.1	1.1	0.0	3.0	11.1	4.6	6.1
Difference	5.9		-3.8		-2.0		-2.5		-1.1		8.1		1.5	

(1:before the PD program; 2:after the PD program)

Findings of the SubQ2

When we consider the participation-level section of Table 4, it is clear that all of the teachers, other than TA and TC, have rates above the weighted participation limit in this dimension. The use of teaching strategies is evaluated in different columns (as R and NR), in accordance with the teachers' position on requiring students to participate in lessons (R: requiring student participation; NR: not requiring student participation).

Table 7. The frequency of the use of teaching strategies and their qualities according to years

	Number of times used				Quality			
Teacher	1 R	2 R	1 NR	2 NR	1 R	2 R	1 NR	2 NR
TB	15	49	10	11	79.9	96.9	87.5	97.2
TD	20	43	14	16	92.2	97.5	81.4	89.0
TE	15	34	10	13	70.2	90.8	64.6	83.9
TF	7	33	11	10	82.4	89.6	66.0	76.9
TG	7	30	11	9	60.1	87.6	50.0	75.7
Average:	12.8	37.8	11.2	11.8	77.0	92.5	69.9	84.5
Difference:	25.0		0.6		15.5		14.6	
TA	13	24	18	13	82.9	96.5	78.4	82.5
TC	2	10	14	11	25.0	77.8	46.9	57.9
Average:	7.5	17	16	12	54.0	87.2	62.7	70.2
Difference:	9.5		-4.0		33.2		7.6	
Total average:	11.3	31.9	12.6	11.9	70.4	91.0	67.8	80.4
Difference:	20.6		-0.7		20.6		12.6	

R-requiring student participation
NR-not requiring student participation
1:before the PD program
2:after the PD program

Table 7 reveals an obvious increase in the use of teaching strategies in both groups after the PD program. This increase is associated with strategies that require student participation. Quality also improved with an increased use of teaching strategies. For strategies that did not require student participation (NR), the number of uses remained almost stable among upper-group teachers and decreased slightly among lower-group teachers. Before the PD program, the quality of strategies requiring student participation was 77.0 points for the upper group and 54.0 points for the lower group, on average. These points increased to 92.5 for the upper group and 87.2 for the lower group, after the PD program. The quality increases associated with the use of strategies requiring student participation were 15.5 points in the upper group and 33.2 points in lower group.

However, even in the case of these teaching strategies, quality increased after the PD program. As a consequence of the PD program, the number of strategies requiring student participation increased from 11.3 to 31.9 in total. Quality rose from 70.4 to 91.0. The use of strategies not requiring student participation decreased from 12.6 to 11.9 after the PD program. At the same time, quality increased from 67.8 to 80.4 among the seven teachers after the program.

Findings of the SubQ3

When we consider the level of teacher participation in Table 4, it is clear that TB, TD, and TF had higher than average rankings for participation in this dimension. Both under and above the weighted participation rate, the groups of teachers increased their use of materials approximately three times after the PD program. The quality of use also increased. On average, teachers used materials/technology 7.9 times and achieved a quality rating of 63.7 before the PD program. The quality figured changed by 24.1, reaching 86.4 after the PD program.

Before the PD program, the upper group had an average rating of 75.5 for material-use quality, while the lower group had a rating of 54.8. These rates increased to 89.7 for the upper group and 84.0 for the lower group of teachers after the PD program. The quality increases associated with the use of materials/technology were 14.2 points in the upper group and 29.2 points in lower group after the PD program. After the PD program, the most frequently used materials were videos (used in the PD program), boards, and lab equipment. The MoNE lesson book and other source books began to be used in a more qualified way to teach more common topics, both inside and outside class.

Findings of the SubQ4

When we look at Table 4, it is clear that TB, TD, and TF are above the line for their participation criteria. The number of formative assessments by upper-level teachers in particular and the significant increase in quality of use are noticeable. According to the observation data, when the seven teachers used tools to carry out a formative assessment, it was generally to answer questions. Formative assessment use was 2.1 before the program, increasing to an average of 5.3 after the program. Quality increased from 58.0 to 78.9. It is clear that the use of summative assessments increased after the PD program. However, the summative assessment use of most teachers did not change. The teachers mainly used summative assessments when giving assignments (investigation).

The observation results show that no teachers used diagnostic assessments before the PD program; only one teacher (TB) used them after the program. The quality of implementation was very high (100%). This particular teacher spent more time participating in the PD program than any other. No teachers used placement tests before the PD program; afterwards, they were used successfully, especially by upper-group teachers.

Results of the Student Group Interviews

O1, O2, O3, O12 and O14 show that there was a 50% or higher change in student opinions in every teacher's observed classes. This post-PD change was obviously positive. In other words, the percentage of students who thought that common topics were not being taught properly after the PD was lower than the number who thought this before the PD. In subject O9, however, there was no significant change in student opinions. Although there was a remarkable decrease in the number of upper-group students who thought that teachers were not teaching common topics well, O9 was considered problematic during both years by students whose teachers were in both the lower and upper groups. Some students explained why they found it difficult to learn some subjects in the unit. A common problem mentioned by students with various teachers in both years was the fast and superficial introduction of scalar and vector quantities.

Discussion and Conclusions

Major Findings and Discussion

The present study created a PD-model framework and examined its effectiveness by assessing teachers' classroom practices. The impact of the PD program, which was implemented as planned, was associated with participation rates. Teacher changes that occurred in four dimensions -content, teaching strategy, materials/technology, and assessment- were investigated. The present study supports earlier studies in confirming the positive impact of a PD program on teacher practices (Dolfing et al., 2021; Heller et al., 2012; Johnson, 2011; Pieters et al., 2019; Pop et al., 2010; Zavala et al., 2007). The present study provides detailed evidence-based results showing the direct effect of PD on teachers' classroom practices. This development model had a positive effect on class teaching in four selected dimensions.

A Discussion of Related Results in Four Dimensions

The more teachers participated in the PD program in each dimension, the more their teaching changed in a positive direction in that dimension. This study shows the importance of obtaining more results by extending interaction times. Teachers who participated in the study were divided into lower and upper groups, in reference to a participation rate of approximately 80% (participation values changed sharply).

Observation results showed that all teachers experienced a positive change in their delivery of common topics after the PD program. Teachers with higher participation rates also experienced a larger increase in the number of common topics they were able to fully deliver. Overall, fewer common topics were partially or incorrectly delivered. No teachers failed to deliver any topics correctly. Teachers emphasized daily life more frequently after the PD program. The failure to deliver common topics, a problem seen during the first observations, was discussed during the PD program; it was presented more clearly during the second observations. In the subjects that students did not feel they had learned properly (according to group interviews), there were clear improvements after the PD program.

The common topics O8, O9, and O11 were widely misunderstood; teachers began to present these more often and more correctly after the PD program; however, the rate did not increase as much as it did in other subjects. Misconceptions can be very difficult to change; extra time and the use of alternative techniques are needed to fix this problem (Singer et al., 2012). The results of the present study show that PD programs, which aim to eliminate misconceptions, need to allocate more time to this problem. The results of this study were compatible with previous NOS research findings, showing that NOS understandings are inconsistent and fragmented. For example, many teachers, who once believed science has a weak structure that can change, now believe that scientific theories can be turned into laws over time (Schwartz et al., 2004). Some students mentioned that they did not learn about hypotheses, theories about O9, or the relationships and differences between them after the PD program. Misconceptions about O11 and O5 and changes to O7 were fairly common. Some NOS concepts (modelling, hypotheses, laws, and theories) were missing after the PD program.

When we examined the observation results in relation to teaching strategies, it was clear that number, variety, and quality of teaching strategies increased after the PD program. One goal of this dimension was to apply more student-centered methods which play dominant role for student learning (NRC, 2015). Teaching methods requiring student participation were used by all teachers in the upper and lower groups. In group interviews carried out after the PD program, students mentioned talking about the various methods used in classes and participating in lessons actively (the exception to this rule were TC's students, who had the lowest levels of involvement in the program). There was no decrease or significant change in the number of teaching strategies (including teacher-centered strategies) that required less student participation.

An examination of the observation results relating to materials/technology revealed an increase in number, variety, and quality after the program. This increase was supported by student group interviews. Students interviewed before the PD program said that they didn't use any materials/technology in lessons; those interviewed after the PD program said that they used various materials/technology more often. The PD program also targeted the appropriate and effective use of books inside and outside class. To enforce this dimension, the teachers were given materials that could be used directly in this unit; they discussed the selected materials among themselves. It is clear that this method is useful. When the teachers were given concrete materials directly and shown how to use them in lessons, they preferred to use those materials more often in their own lessons.

When the teachers assessed common topics, they tended to use summative-purpose assessments, in the form of traditional written exams. This was true for all teachers in the upper and lower groups, before the PD program. Placement and diagnostic assessments, less well-known forms of assessment, were never used before the PD program. After the program, TB, who participated more energetically in the program than any other teacher, used these two assessment methods in the most effective way after the PD program. In general, this program increased the teachers' awareness of these types of assessment, which are used for a range of different purposes. Formative assessments increased and were used in a better way after the program. In interviews, the students said that their teachers gave them more feedback and tested what they had learned more often after the PD program.

Although each dimension was given nearly the same level of importance in face-to-face interactions, the teachers paid less attention to the assessment dimension in non-face-to-face interactions. Seven teachers spent 35 minutes on average on the assessment dimension in non-face-to-face communications. By contrast, they spent 160 minutes on content, 136 minutes on teaching strategy, and 75 minutes on materials/technology. To motivate them, some documents and questions about assessment were uploaded to the social media group; even though discussion environments were created, the teachers remained less interested in this area. Teachers communicated more about teaching strategies and the use of materials in their non-face-to-face interactions. The teachers may have seen content, teaching strategies, and material as closely related topics that should be considered as a group. They may have seen assessment as a separate task needing extra attention.

Implications

The present study proves that teachers who achieve a high participation rate in a professional development program achieve more positive results during in-class teaching. We therefore advise future researchers to consider the participation rate in PD programs and take steps to increase the number of hours that teachers spend participating in the program. Teachers who participated for many hours in this study improved their delivery of common topics, use of teaching strategies, and use of materials/technology. It was observed that the teachers had deficiencies in the assessment domain, due to past experiences. These findings suggest that teachers need more knowledge and practice in class assessment during pre-service and in-service training. Similarly, it can be useful to consider learning theories at the professional-development stage. Researchers are advised to include questions about the content of programs, as well as general questions, in need-assessment surveys.

The model developed for this study was created by integrating 12 professional-development characteristics into the program at different levels. As Luft and Hewson (2014) have suggested (and the research results show), studies should integrate components and examine their effects, rather than measuring only one PD characteristic. In PD programs, models that focus on teachers are more effective than lectures by people deemed to be "experts" in the field. Still, educators can be invited to offer support, in accordance with teacher needs. PD programs run by experts should include mutual communication, rather than single-direction lecturing (Wheeler et al., 2015).

Recommendations

This study has explained the development process using five phases. In the literature, these development processes are not explored in detail (Stolk, de Jong, Bulte, & Pilot, 2011). The same study could be used to test a larger or different sample; it could also be applied to different disciplines.

The PD program was unable to provide a teacher-teacher communication environment before the training began. This type of communication could be achieved by including a longer period of time before the program. Preliminary preparation can familiarize teachers with the PD programs. This approach should be tried and tested in future PD programs. Future programs should include teachers as are active participants and involve them in practical applications. PD for teachers can be increased through face-to-face and non-face-to-face interactions (via computer networks and telephone calls). Hybrid learning environments can thus be used for PD programs, providing teachers with a supportive system for learning (Elster, 2010).

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in JESEH journal belongs to the authors.

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