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Teachers' Professional Development for Implementing STEM Education: Implications for Teacher Development Program

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Abstract
This study examines barriers to teachers' professional development for the implementation of STEM education. Challenges associated with STEM integration, inquiry-based activities, integration of Instructional Technology, student-centered learning, and other similar areas were examined. The study used a survey to assess teachers' professional development in STEM education, their knowledge, skills, training, and the challenges they face. The survey also assesses the teachers' professional learning needs. The study uses a quantitative approach to provide insights on teachers' preparedness to integrate STEM and the different obstacles that may impact this preparedness. The results of the study will provide evidence on the existing gaps in professional development and inform the design of appropriate and contextual professional development programs. This study has theoretical and practical implications on policy, practice, and research to strengthen STEM teaching. The study informs teacher educators, school leaders and policy makers on the design and implementation of professional development programs on the effective integration of STEM education in classrooms.
Keywords: Teacher development program, STEM education, teacher professional development, teacher preparedness

Introduction
There has been a huge push in recent years towards STEM (science, technology, engineering and mathematics) education as a result of the rapid advances in these fields and the increased demand for approaches to deal with complex problems and for the integration of knowledge to get to solutions. STEM is now very much in vogue as a way of meeting this demand. It is all about inquiry in science and math and the application of technology and engineering. It is an inherently interdisciplinary approach which brings the various STEM disciplines together. The problem has been that in the past these subjects have been taught in isolation and for true integrated STEM to work it has to be embedded in the curriculum, the classroom resources and the teaching approaches. For effective integration and implementation of STEM education you do need specific teacher professional development. The teachers themselves need to be able to integrate the disciplines and to see the 'big picture' when it comes to addressing a question or a problem (Dare et al., 2021). They need to be able to foster creativity and provide students with the opportunity to work collaboratively on real problems. The teacher is absolutely central to the achievement of the aims of STEM education and therefore teacher professional development is key to the successful integration and implementation of STEM education reforms.
Despite the growing international focus on STEM education, teachers continue to face difficulties in translating the various interdisciplinary aims into their actual classroom practice.

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CJSSR
CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
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The problems they face are a range of issues including lack of preparation in the integration of the disciplines, low levels of confidence in teaching engineering and technology, difficulty in designing inquiry based activities and the practical constraints of time, resources and assessment. Teachers who have been trained in a disciplinary way are likely to find it very difficult to bridge the gap between the scientific and mathematical concepts and the engineering design and technology applications (Chalmers et al., 2017). The existence of a STEM curriculum is therefore no guarantee of its actual implementation. Professional development is thus key to the development of teachers' interdisciplinary understanding, their pedagogical knowledge, their confidence and their ability to design and deliver integrated STEM learning. Research has shown that effective teacher professional development (TPD) needs to go far beyond a one-off workshop or the simple transmission of subject knowledge. Lo (2021) in a systematic review of 48 empirical studies found that content knowledge, pedagogical content knowledge and access to instructional materials were the most commonly reported components of TPD for integrated STEM. The review also identified a number of persistent pedagogical and structural barriers to TPD including lack of teacher expertise, lack of preparation time and lack of resources. The implication of this is that TPD should be designed with the practicalities of teaching STEM in mind rather than simply focused on the development of theoretical understanding.

The design and organization of STEM professional development is just as important as the content of the development itself. Surahman and Wang (2023) looked at 44 studies of in-service STEM teacher professional development published between 2018 and 2022 and found that the most common forms of PD were workshops, training and online PD. Their review also found that constructivist learning theories were the dominant theoretical underpinning of the programs they looked at and highlighted the importance of school leaders in facilitating teacher professional learning. This is supported by Boz (2023) who reviewed the empirical literature on professional development for integrated STEM in primary schools and provided further evidence of the nature of the emerging PD programs for this type of teaching. Collectively the literature points to the need for sustained professional learning, practical engagement, collaboration and institutional support.

A key issue in the development of effective STEM professional development is the extent to which the content of the program matches the competencies that teachers actually need to demonstrate in the classroom. The competencies in question may be those of understanding the inter-disciplinary links in STEM, designing integrated STEM activities, facilitating inquiry and engineering design, using technology appropriately, managing collaborative learning and assessing the application of knowledge. There is also evidence from South Korean secondary teachers that there is a gap between the perceived importance of the various integrated STEM teaching competencies and the extent to which they are actually demonstrated in the classroom (Song, 2020). This highlights the importance of identifying the actual competencies that teachers require in order to be able to deliver effective STEM teaching, rather than simply assuming that attending a PD program will in itself lead to improved practice.

The purpose of this study is to determine what types of professional development opportunities teachers require and what resources are available in order to design effective teacher development programs in the area of STEM education. An understanding of the teachers' own knowledge, skills and experience as well as the problems they encounter will go some way towards identifying the types of professional development that are required at the local level to

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CJSSR
CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
Vol.04 No.01 (2026)

enable teachers to achieve their own aims in the teaching of STEM. There is a great deal of interest in the evidence base relating to the teaching and learning of STEM education amongst teacher education institutions and educational policy makers as they seek to address the issue of teacher professional development and education in order to achieve the aims of curriculum integration. The study therefore aims to establish what teacher professional development programs and opportunities are currently in place to assist teachers in achieving their aims in the teaching of STEM, what the barriers to this are and what information teachers need in order to design effective teacher development programs for STEM education. The study is designed to produce information which will be of direct relevance to practitioners and decision makers in the area of teaching and learning of STEM education. The following are the research questions:

1. What are the demographic and professional profiles of teachers (in terms of gender, level of teaching, STEM training, academic qualification and subject specialism) in terms of their preparedness to deliver STEM education? Is there a significant difference?
2. To what extent do PD experiences and STEM training and related activities predict teacher preparedness to implement STEM?

Review of Related Literature

The implementation of STEM education requires teachers to adopt a cross-disciplinary approach in order to promote learning through a range of different approaches and strategies that are based on investigation and inquiry, collaboration and critical thinking (Yang et al., 2026). The effective integration of STEM education will require a degree of intentionality and planning on the part of the teacher and active engagement on the part of the teacher. This in turn is dependent upon the teacher's professional knowledge and pedagogical skills, their level of training and their willingness to integrate STEM into their teaching (Singh, 2024). It is clear that teachers face a number of difficulties when attempting to integrate the disciplines in STEM, in the creation of integrated learning experiences, in the use of a range of different teaching tools and in the integration of technology and engineering into their teaching practice, thereby highlighting the need for ongoing professional development (Margot & Kettler, 2019; Surahman & Wang, 2023). Professional development is of key importance in terms of enhancing teachers' knowledge of the disciplines of STEM as well as in the development of their ability to use a range of cross-disciplinary pedagogies (Rehman et al., 2025). The extent to which teachers are prepared to integrate STEM education will vary according to their demographic and professional characteristics (gender, length of teaching experience, level of education and subject specialism). It is therefore equally important to consider the professional factors which statistically account for the level of preparedness of teachers. This review of the literature will focus on teacher preparedness to integrate STEM education, the differences in preparedness by demographic and professional characteristics and the extent to which STEM-related training and professional development can be used to predict levels of preparedness.

Teachers' Preparedness for Implementing STEM Education

Teachers' preparedness for implementing STEM is their readiness to deliver STEM in the classroom using their own knowledge, skills, confidence and pedagogy. The aim of STEM is to equip students with the skills needed to go on to careers in engineering and technology and in other related areas of science and math (Papagiannopoulou & Vaiopoulou, 2024). In traditional subject teaching the teacher is expected to have the subject knowledge to be able to explain the

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CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
CJSSR
CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
Vol.04 No.01 (2026)

subject to the class and the student learns by listening and sometimes by observation. In STEM teaching however the teacher is expected to make the connections between the disciplines and to facilitate students in engaging in research and learning activities so that they develop the skills to analyze and interpret their environment and to design artefacts. The teacher therefore needs to be able to plan lessons which will enable the students to acquire these skills and to engage in a series of learning activities.

Margot and Kettler (2019) identified a range of issues in the teachers' experience of STEM integration: pedagogical, curricular, structural and assessment related. The significance of teachers' instructional knowledge and the level of support they have within the school is highlighted. These are all issues of preparedness in that the teacher may have a good grasp of what STEM is and what it is for, but may still find it very difficult to actually deliver it in the classroom. Professional development can play a role in addressing this by improving the teachers' pedagogical knowledge and their ability to actually use STEM in the classroom. Preparedness is also linked to the extent of opportunity that teachers have to engage in practical STEM learning. Professional learning that involves collaborative lesson planning, curriculum integration, engineering design and classroom based experimentation could be a way of helping teachers to make the connection between what they know and what they do in the classroom. Preparedness is therefore a multi-faceted concept which can be understood in terms of both the teacher's sense of capability and the opportunities they have to develop that capability.

Differences in Teachers' Preparedness by Demographic and Professional Characteristics

Teachers' demographic and professional characteristics may be related to differences in teachers' perceived preparedness to deliver STEM education. Gender, academic qualification, teaching experience and subject specialism may all be indicative of different levels of teacher training and educational backgrounds, different roles and responsibilities as classroom teachers and as teachers in schools (e.g. as supervisors), and different levels of exposure to and engagement in STEM-related professional development. It is of course necessary to look at these relationships to see whether or not there is any real evidence to support the claim that teachers are prepared to deliver STEM. A good deal of research into teacher confidence, self-efficacy and STEM related professional learning will include gender as a demographic variable. Teachers' own experiences and confidence will be relevant to their sense of preparedness. It would be unwise to assume that there are gender differences in all aspects of preparedness. For instance a 2025 quantitative study of 59 in-service teachers taking part in an online course on technology integration found that there was an increase in the participants' sense of value of STEM and in their pedagogical self-efficacy (Wu & Zhou, 2025). There was also no difference in these outcomes by gender. It would therefore be prudent to look at the specific context and participants of the current study before making any conclusions about the relationship between gender and teachers' sense of preparedness to teach STEM.

Teaching experience can be a contributor to preparedness in that it provides the opportunity to develop classroom management skills, to adapt your teaching, to respond to the needs of learners and to hone your pedagogical decision making. Experience in traditional subject teaching however does not necessarily equate to experience in interdisciplinary STEM teaching. A teacher with a great deal of teaching experience may well have developed considerable subject and classroom expertise but have very little experience in engineering design, in the integration of technology or in the planning that is required for interdisciplinary work. On the other hand a less

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CJSSR
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experienced teacher may have had more exposure to STEM oriented preparation but have had fewer opportunities to actually apply that. Goldhaber et al. (2023) used survey and administrative data on early career STEM teachers in Washington State to look at how field experiences and classroom contexts were related to teachers' perceptions of their own preparation. Their work is consistent with the view that we need to consider preparation experiences and professional context in addition to the characteristics of the individual teacher when we are looking at perceived preparedness. Academic qualifications may well contribute to a teacher's subject and pedagogical knowledge but a higher level of qualification does not necessarily equate to ability and competence to teach STEM Integration. Having postgraduate qualifications may have given teachers the opportunity to deepen their subject knowledge and/or to take part in professional development in the area of STEM teaching. The relationship between academic qualifications and a teacher's sense of preparedness to teach STEM Integration should therefore be examined in the context of other teaching related qualifications.

Integrated STEM education requires teachers to be engaged in multi-disciplinary teaching. The degree of teacher specialization in the subject areas is therefore key. A science teacher may be very good at scientific inquiry but may not be equally good at teaching engineering design. A math teacher may be very good at mathematical reasoning but may not be as good at teaching the integration of science and engineering. The degree of specialization of the teachers is important in identifying potential gaps in the teachers' own perceived preparedness. The areas of gap identified in this way may form the basis of the need for interdisciplinary teaching practices. With that in mind, teachers will be prepared in different ways to deliver integrated STEM across different demographic and professional groupings. It is important to stress that any differences that are found and documented through statistical tests should be interpreted as associations within the study sample. One should be very cautious in ascribing any of these differences to cause.

Professional Development Experiences and Teachers' STEM Preparedness:

Professional development opportunities allow teachers to build on their subject knowledge, develop their pedagogy, explore new instructional technologies and gain experience in delivering integrated STEM activities. In the STEM context the range of PD can be quite broad and may include formal workshops, short courses, online learning, collaborative lesson planning, mentoring, research and school-based support. The value of such experiences is not just in the fact that they are undertaken but in the content of the experience, the length of it, the degree to which it is practical and how it relates to the teachers' actual classroom work. Surahman and Wang (2023) in a systematic review of 44 studies from 2018 to 2022 found that workshops, training and online PD were the most commonly used forms of in-service STEM teacher development. The review also identified constructivist learning theory and school leadership as key enablers of professional learning. The implication of this is that PD should provide teachers with the opportunity to actively construct knowledge and apply what they have learned, and that school leadership can provide the necessary conditions for that to happen.

There is also empirical evidence that professional development can be linked to increased teacher preparedness and changes in teaching practice. Stieben et al. (2021) looked at research experiences and online PD for middle and high school teachers and found that both were associated with greater perceived preparedness to use the targeted STEM teaching methods and with an increased frequency of use of those methods. Teachers who had taken part in the summer

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CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
CJSSR
CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
Vol.04 No.01 (2026)

research experiences also reported some additional benefits. This is of relevance to the current study as it demonstrates how PD that goes beyond the traditional' information transfer' model can help teachers build confidence and capacity. Zhou et al. (2023) conducted a meta-analysis of 21 studies involving 1,412 in-service STEM teachers and found a positive overall effect of PD on STEM teaching self-efficacy. Their study also highlights the importance of the PD being based on STEM pedagogy. Given that self-efficacy and preparedness are related but distinct constructs, the findings support the value of professional learning in building teacher confidence without necessarily implying that self-efficacy and preparedness are the same thing.

For this study professional development experiences could be considered a predictor of perceived preparedness. In that case it would be expected that teachers who have had recent, relevant STEM professional development experiences would have higher levels of perceived preparedness (as they would have had the opportunity to know, practice and experience integrated STEM teaching). The quality and relevance of the professional development experiences is likely to be more important than the quantity.

Experience, Training, and Preparation as Predictors:

In addition to looking at teachers' experiences of professional development, looking at teachers' experience and training in STEM-related activities as potential predictors can provide further insight into teachers' perceived preparedness. Multiple regression can be used to assess the individual contribution of each predictor whilst taking the others into account. Given that teachers' training, years of experience and exposure to STEM education may all overlap, this is a useful approach. Teaching experience (including training and practice in teaching) may in various ways contribute to teachers' preparedness (e.g. in the effective use of a range of teaching resources and strategies and in having a deep understanding of the various elements of the school's curriculum). Teacher preparation is of course of value to teacher practice. The relevance and contribution of teacher preparation may however be contingent on a number of factors, with one such factor being the extent to which teachers have had the opportunity to participate in professional development which builds their capacity to teach in a trans-disciplinary or interdisciplinary manner. Years of teaching experience alone may not necessarily indicate the nature or relevance of teachers' learning. It is therefore important to consider teacher preparation in the context of teachers' teaching experience and training rather than simply viewing experience as a proxy for competence to teach STEM.

STEM related training is another potentially important predictor as it provides the opportunity to work with integrated curricula, inquiry based learning, engineering design, technology integration and interdisciplinary assessment. The evidence from Stieben et al (2021) and Zhou et al (2023) is consistent with looking at the contribution of structured professional learning to teachers' preparedness related outcomes. The degree to which this relationship holds in a particular context will of course need to be established through data from the teachers in question. A multiple regression model that includes professional development experience, teaching experience and STEM related training can be used to determine how much of the variation in perceived preparedness is statistically accounted for by these variables. The model can also be used to determine whether professional development experience makes a unique contribution to the prediction of preparedness once teaching experience and STEM related training are taken into account. Such findings would be of value in terms of identifying professional learning priorities and in the design of teacher development programs. As this is a

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CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
CJSSR
CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
Vol.04 No.01 (2026)

quantitative study and if cross-sectional would be observational, the regression results should be interpreted as statistical prediction rather than as evidence of causal effects.

The literature reviewed indicates that teacher preparedness has an impact on the implementation of STEM and that teacher training can contribute to the development of teachers' knowledge of how to teach STEM, their confidence in doing so and their use of STEM pedagogies. The existing research focuses on the challenges that teachers face, the characteristics of the professional development programs that are available and the potential of structured training to improve the quality of STEM teaching. The relationship between the individual professional characteristics of teachers and their level of preparedness is however contextual. There are three reasons for undertaking the present study. Firstly, the degree of preparedness that teachers bring to the role due to factors such as gender, length of teaching experience, academic qualification and subject specialization will be context specific rather than generalizable. Secondly, in the same study it would be useful to examine the relative contribution of professional development, teaching experience and STEM specific training to teacher preparedness and to determine how these relate to one another in a single model. Thirdly, such an understanding would provide the basis for information as to which teacher development programs might be offered to teachers depending on their professional background and learning needs. For these reasons the present study investigates whether there are differences in the level of perceived preparedness across the study population as a function of demographic and professional characteristics. It also seeks to identify the predictors of professional development, teaching experience and STEM specific training. The findings are expected to provide a basis for the development of more targeted and contextually appropriate professional development opportunities for teachers.

Theoretical Foundation of the Study

The theoretical underpinning of Teachers' Professional Development for Implementing STEM Education: Implications for Teacher Development Program is the integration of two perspectives. The first is Shulman's framework of Pedagogical Content Knowledge (PCK). The second is Demimonde’s conceptual framework of teacher professional development.

Shulman (1986, 1987) wrote about PCK in order to describe the body of knowledge and the associated pedagogical skills that teachers need in order to facilitate learning. In the context of this study PCK is used to describe the integration of content in order to achieve the aims of STEM education. STEM education is inherently interdisciplinary in nature and involves learning that goes beyond the confines of a single subject area (interdisciplinary lesson planning, integrative instruction, etc) with the aim of engaging students in learning activities which promote problem solving and reflection. According to the PCK framework, teachers' academic and teaching qualifications and specialisms may be linked to differences in their ability to integrate content. The PCK framework is used in this study to assess the extent to which teachers are equipped in terms of their professional background and their pedagogical content knowledge.

Desimone's (2009) framework outlines the five key features of professional development that are most likely to lead to improvements in teacher knowledge and practice: content focus, active learning, coherence, duration and collective participation. All of these are relevant to STEM education as teachers need the opportunity to develop their knowledge of STEM content in a practical and applied way and to learn and use STEM pedagogy. Professional development that is specifically focused on STEM, that involves active learning, is coherent, of sufficient duration and includes collective participation is likely to be the kind of experience that would lead to

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CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
CJSSR
CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
Vol.04 No.01 (2026)

greater preparedness to teach integrated STEM. The framework therefore provides a basis for looking at professional development and STEM specific training as potential predictors of teacher preparedness.

The two theories dovetail to provide a framework for the analysis of the key elements of the research. Shulman's PCK framework enables us to identify the knowledge and pedagogical competencies that are indicative of teacher preparedness and Desimone's framework enables us to identify the characteristics of professional development that facilitate the development of these competencies. The combined theoretical framework enables us to place teachers' preparedness in terms of their existing professional knowledge and the opportunities for the further development of that knowledge through professional learning. It therefore provides a basis for examining differences in teachers' professional backgrounds and for determining the statistical impact of professional development, teaching and STEM specific training. This is the information we need in order to develop appropriate teacher development programs.

Methodology

The study used a quantitative, cross-sectional survey design to look at teachers' preparedness to deliver Science, Technology, Engineering and Mathematics (STEM) and a number of related professional factors. A quantitative approach was taken as the study was concerned with the numerical expression of teachers' preparedness, the comparison of preparedness across various demographic and professional groups and the extent to which professional development, teaching experience and STEM-related training could be used to predict preparedness. The cross-sectional design allowed the researchers to collect data from teachers at a single point in time. The study sought to answer two research questions. The first was whether there were differences in teachers' preparedness to deliver STEM according to their gender, teaching experience, academic and professional qualification and specialisation. The second was to determine how professional development, teaching experience and STEM-related training would predict teachers' preparedness. As the data were collected at a single point in time the regression results were interpreted as indicating statistical relationships rather than causality.

Participants and Sampling

The study population consisted of teachers of science, technology, engineering and mathematics (STEM) subjects and related disciplines at the institutions in question. The teachers were those with the potential for exposure to STEM related pedagogical practices and who were in the classroom. Purposive sampling was used to select the participants from the target population. The final sample was 60 teachers. The teachers' teaching experience ranged from 5-10 years. The sample represented a range of subject specialisms. Participation was voluntary. Only those teachers who met the defined inclusion criteria were invited to take part in the study. Teachers who did not have classroom teaching responsibilities or who did not complete the questionnaires were excluded from the study.

Research Instrument

Data were collected via a structured questionnaire designed to assess teachers' experiences and preparedness in relation to their professional development in the area of STEM education. The questionnaire was adapted from Ayyoobi et al. (2016) and Khut (2024). The items measuring the key constructs were rated on a 5-point Likert scale (1 = strongly disagree to 5 = strongly agree). Composite scores were derived for the various scales following an examination of the

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CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
CJSSR
CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
Vol.04 No.01 (2026)

instrument's reliability. Higher scores indicated a higher level of the respective construct. The content validity of the instrument was established through review by two experts in the areas of STEM education, teacher education, educational measurement and educational technology. The experts reviewed the items in terms of their relevance, clarity, comprehensiveness and appropriateness in relation to the constructs under investigation. On the basis of their feedback, some of the items were revised or deleted prior to the final administration. The internal consistency of the instrument was assessed using Cornbrash's alpha (α) which was found to be 0.846.

Data Collection Procedure

Following approval from the appropriate institutional authorities and completion of the requisite ethical procedures, data were collected from the selected teachers. The participants were made aware of the purpose of the study, the voluntary nature of their participation, the confidentiality of their responses and their right to withdraw at any time without penalty. The questionnaire was administered by the researcher and participants were given ample time to complete it. The completed questionnaires were then checked for completeness prior to being entered into the statistical software. Any responses that were incomplete and did not meet the pre-determined inclusion criteria were excluded from the final dataset.

Data Analysis

The data were analyzed using IBM SPSS Statistics Version 29.0. Both descriptive and inferential statistical techniques were used in line with the research questions. Descriptive statistics (frequencies, percentages, means (M), standard deviations (SD)) were calculated to describe the demographic characteristics of the participants and the key study variables. To answer the first research question we looked at differences in teachers' preparedness according to their demographic and professional characteristics. An independent samples t-test was used for variables with two groups (e.g. gender) and one way ANOVA was used for variables with three or more groups (e.g. academic qualification, subject specialism). Where there was a statistically significant omnibus ANOVA result we carried out the appropriate post hoc test to determine which specific groups were significantly different from each other. To answer the second research question a linear regression analysis was carried out to determine the extent to which teachers' professional development experience, teaching experience and STEM training predicted their level of preparedness for implementing STEM. Teachers' preparedness was the dependent variable and professional development experience, teaching experience and STEM training were the predictor variables.

Results

Table 1: Descriptive statistics of the participants' demographic characteristics (N=60)

Sr. No.	Variable	Category	Frequency	Percentage
1	Gender	Male	14	23.3
		Female	46	76.7
2	Academic Qualification	Bachelors	28	46.7
		Masters	27	45.0
		PhD	5	8.3
3	Subject Specialization	Science	22	36.7
		Technology	14	23.3
		Engineering	12	20.0

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CJSSR
CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
Vol.04 No.01 (2026)

		Mathematics	12	20.0
4	Teaching Level	Primary	3	5.0
		Middle	14	23.3
		Secondary	16	26.7
		Higher Studies	27	45.0
5	STEM training	Yes	19	31.7
		No	41	68.3

Table 1 shows the demographic and professional profile of the 60 participants in the study. On gender terms the majority were female (n=46, 76.7%) with 14 (23.3%) male. With regard to academic qualification 28 (46.7%) had a BSc, 27 (45.0%) had a postgraduate qualification (MSc) and 5 (8.3%) had a PhD. This shows that the majority of participants had either a BSc or MSc. In terms of subject specialism 22 (36.7%) were science specialists, 14 (23.3%) were technology specialists and 12 (46.7%) each were engineering and mathematics specialists. Science was by far the most represented specialism with engineering and mathematics being equally represented. In terms of teaching level 27 (45.0%) were associated with higher education, 16 (26.7%) taught at secondary level, 14 (23.3%) at middle level and 3 (8.3%) at Primary level. Higher education was by far the most common teaching level with primary level being the least represented. With respect to previous STEM training 19 (31.7%) of the teachers reported having received some form of STEM training whereas 41 (68.3%) reported that they had not. This indicates that just under two-thirds of the participants had not received any STEM training. The relatively low proportion of trained teachers suggests a clear need for more effective professional development to support teachers in the delivery of integrated STEM.

Table 2: *Independent sample t-test for mean difference between male and female teachers' perception about teachers' professional development for implementing stem education*

Gender	N	Mean	df	t	Sig.
Male	14	106.14	58	-1.467	0.148
Female	46	112.13			

An independent samples t-test was carried out to determine whether there was a significant difference in the way male and female teachers perceived professional development for the implementation of STEM. As shown in Table 2, the male teachers (*n=14) ha*d a mean score of 106.14 whereas the female teachers (*n=46) ha*d a higher mean score of 112.13. The difference between the two groups was not statistically significant however, $t(58) = -1.467$, $p = .148$. As the *p*-value is greater than the conventional level of .05 the null hypothesis of no significant gender difference in perception of professional development for the implementation of STEM is not rejected. The females scored higher on average than the males but the results do not provide sufficient statistical evidence to conclude that there is a significant difference in perception of professional development for the implementation of STEM by gender in this sample.

Table 3: *Independent sample t-test for mean difference between teachers' perception about teachers' professional development for implementing stem education based on STEM training*

Gender	N	Mean	df	t	Sig.

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CJSSR
CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
Vol.04 No.01 (2026)

Yes	19	102.57	58	-3.470	0.001
No	41	114.51			

Table 3 presents the results of an independent samples t-test to determine whether there was a difference in teachers' perceptions of the professional development of STEM Education according to their own previous STEM training. The group who had received STEM training (n=19) had a mean score of 102.57 whereas the group who had not received any STEM training (n=41) had a mean score of 114.51. The difference between the two means was statistically significant, t(58) = -3.470, p = 0.001. As the p-value is less than 0.05 the null hypothesis (that there is no significant difference between the means of the two groups) is rejected. It is therefore concluded that teachers' perceptions of the professional development of STEM Education did differ according to their own previous STEM training and that the mean of the group who had not received any STEM training was higher than that of the group who had received STEM training.

Table 4: *One way ANOVA for mean difference between teachers' perception about teachers' professional development for implementing stem education based on academic qualification*

Comparison	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2664.617	2	1332.308	9.386	.000
Within Groups	8091.117	57	141.949		
Total	10755.733	59			

Table 4a: *LSD Post Hoc analysis for mean difference between teachers' perception about teachers' professional development for implementing stem education based on academic qualification*

Comparison variable	Mean difference	Sig.
PhD vs Masters	22.82	0.000

A one way ANOVA was conducted to determine if there were any differences in teachers' views of the professional development required to implement STEM education according to their level of academic qualification. There was a significant effect of academic qualification on teachers' views of professional development, F (57) = 9.39, p < .001, η^2 = .248. The effect size indicated that academic qualification accounted for around 24.8% of the variance in teachers' views of the professional development required to implement STEM education. A post hoc LSD analysis revealed a significant mean difference between the PhD and master's degree groups (MD = 22.82, p < .001). This confirms that teachers' views of the professional development required to implement STEM education are in fact related to their level of academic qualification. The

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CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
CJSSR
CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
Vol.04 No.01 (2026)

findings further highlight the importance of taking teachers' levels of education into account when designing professional development for the implementation of effective STEM education.

Table 5: *One way ANOVA for mean difference between teachers' perception about teachers' professional development for implementing stem education based on subject specialization*

Comparison	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3251.853	3	1083.951	8.089	.000
Within Groups	7503.880	56	133.998		
Total	10755.733	59			

Table 5a: *LSD Post Hoc analysis for mean difference between teachers' perception about teachers' professional development for implementing stem education based on subject specialization*

Comparison variable	Mean difference	Sig.
Science vs Math	18.93	0.000

A one way ANOVA was carried out to look at differences in teachers' views of PD for STEM teaching according to their subject specialism. There was a statistically significant difference between the groups, F (56) = 8.09, p < .001, η^2 =.302. The effect size indicated that 30.2% of the variation in teachers' views of PD was attributable to their subject specialism. The LSD post hoc test revealed a statistically significant mean difference between science and math teachers (MD = 18.93, p < .001). In other words, PD for science and math teachers to deliver STEM needs to be different, and it needs to be tailored to the specific views of each group in order to address their particular challenges and improve their practice.

Table 6: *One way ANOVA for mean difference between teachers' perception about teachers' professional development for implementing stem education based on teaching level*

Comparison	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1703.142	3	567.714	3.512	.021
Within Groups	9052.591	56	161.653		
Total	10755.733	59			

Table 6a: *LSD Post Hoc analysis for mean difference between teachers' perception about teachers' professional development for implementing stem education based on teaching level*

Comparison variable	Mean difference	Sig.
Primary vs secondary	25.02	0.003

A one way ANOVA was carried out to look at differences in the perception of PD of STEM education by teaching level of the teachers. There was a statistically significant difference across teaching levels (F(56) = 3.51, p = .021) with an eta squared of .158 suggesting that teaching level accounted for around 15.8% of the variance in the teachers' perception. The LSD post hoc analysis also revealed a statistically significant mean difference between primary and secondary teachers (MD = 25.02, p = .003). It can therefore be concluded that there are significant

ISSN E: 3006-1466
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CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
CJSSR
CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
Vol.04 No.01 (2026)

differences in the PD of primary and secondary teachers. It is clearly important to have PD programs that are contextualized to the specific needs of teachers at different levels.

Table 7: *Regression analysis for the effect of teachers' professional development for implementing stem education*

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.838[a]	.703	.697	4.60769

a. Predictors: (Constant), STEM
b. Dependent Variable: TPD

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2908.264	1	2908.264	136.983	.000[b]
	Residual	1231.386	58	21.231		
	Total	4139.650	59			

a. Dependent Variable: TPD
b. Predictors: (Constant), STEM

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-15.734	6.001		-2.622	.011
	STEM	1.235	.106	.838	11.704	.000

a. Dependent Variable: TPD

A simple linear regression was carried out to examine the impact of STEM education on teachers' professional development (TPD). The regression model was found to be statistically significant ($F(58) = 136.98$, $p < .001$). The model summary revealed a very strong positive correlation between STEM education and TPD ($R = .838$), with approximately 70.3% of the variance in TPD being accounted for by STEM education ($R^2 = .703$, adjusted $R^2 = .697$).

Discussion

The study looked at what teachers thought about professional development in the area of STEM education and how their views differed according to gender, prior training in STEM, academic qualification, specialism and level of experience. The findings point to the need for contextually appropriate development of teachers and demonstrate that teachers at all levels of experience have different views as to what areas of development and training they would like to see. It can be concluded that teachers' views on the nature of professional development are linked to a range of professional attributes. A regression analysis of the data showed that of all the variables considered, only STEM education was a significant predictor of professional development. These findings are of course specific to the area of STEM education where the focus is on the development of teachers' subject knowledge and their ability to facilitate learners in the construction of understanding of the big ideas.

The independent samples t-test revealed no significant difference in the views of male (M = 106.14) and female (M = 112.13) teachers with regard to professional development for STEM

ISSN E: 3006-1466
ISSN P: 3006-1458
CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
CJSSR
CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
Vol.04 No.01 (2026)

education, t(58) = -1.467, p = .148. So for the purposes of this study gender did not appear to be a differentiating factor in terms of the provision of professional development. There was however a significant difference between those teachers who had undertaken STEM training and those who hadn't, t(58) = -3.470, p = .001. Surprisingly the group of teachers who hadn't had any prior STEM training actually had the higher mean score (M = 114.51) than the group who had (M = 102.57). This is of course an outcome which merits attention. One possible explanation for this is that the untrained teachers may be more aware of their own unmet professional learning needs. The trained teachers may in contrast be more critical of the current provision after having experienced it. Alternatively the difference could be down to the quality, length, relevance or practicality of the training they had previously undertaken. These are all reasonable interpretations rather than conclusions drawn from the data in the present study. The study didn't actually go on to look at why the untrained group scored higher. The literature supports the notion that it is the quality and design of the PD that is important rather than simply the fact that a teacher has participated in it.

Surahman and Wang (2023) in a systematic review of 44 studies on in-service STEM teacher professional development found that workshops, training and online learning were the most common forms of PD, with a clear call for greater institutional support for teacher development. Zhou et al (2023) also found a positive effect of PD on STEM teachers' self-efficacy across the experimental studies they reviewed. The difference between that body of evidence and the finding in the present study is not in any way inconsistent. The studies look at different outcomes and the present study is looking at perceptions according to training history rather than measuring change pre and post an intervention. The present result should not be read as evidence that STEM training has a negative impact on teacher development at all. It simply points to the need to consider whether the training provided actually meets teachers' needs, provides opportunities to actually teach integrated STEM and provides some form of follow-up. Future research should look at the content and quality of the training that teachers have had, their experiences of implementing it and any changes in their classroom practice.

The one way ANOVA revealed statistically significant differences in teachers’ perceptions of PD according to academic qualification, F(2, 57) = 9. 39, p <. .001 (estimated effect size.). So approximately 24. 8% of the variance in the perception scores was accounted for by the differences between the qualification groups. The LSD post hoc analysis found a significant mean difference between the PhD and master' s group (MD = 22. 22.82, p <. .001). This would suggest that academic qualification is in some way relevant to teachers' understanding of PD for STEM. Teachers with different levels of academic qualification may have had different levels of exposure to educational research, interdisciplinary approaches to teaching, curriculum design and inquiry based pedagogy. The data do not tell us which of those factors is responsible for the difference. The direction of the PhD/master' s difference should also be checked from the group means and the order of subtraction used in the post hoc analysis. This finding is in line with the general argument that effective STEM teaching requires both disciplinary knowledge and pedagogical knowledge. Huang et al. (2022) in their systematic review of STEM teacher PD in the K–12 context found that pedagogical knowledge and pedagogical content knowledge were the two main areas of focus in PD programs. They also identified a number of approaches that were used in the programs such as learning by design, learning by doing, reflective learning and group work. These approaches are relevant across qualification levels as a PhD does not

ISSN E: 3006-1466
ISSN P: 3006-1458
CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
CJSSR
CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
Vol.04 No.01 (2026)

necessarily mean that the individual has the requisite knowledge to integrate science, technology, engineering and math in the classroom. The implication is that PD programs should provide different pathways of learning whilst maintaining common standards for integrated STEM teaching. Teachers who are at the stage where they need to develop their skills in the integration of STEM would benefit from a more structured introductory program, whilst those who are at a more advanced stage may benefit from project based design, mentoring, curriculum leadership and collaborative action research. The pathways should be designed around demonstrated competencies and individual learning needs rather than qualification alone.

The results also showed statistically significant differences in teachers' perceptions according to subject specialism, F(3, 56) = 8. 09, p <. .001 (estimated effect size of .). Around 30. 2% of the variance in the perception scores was attributable to the differences between the subject specialism groups. The LSD post hoc analysis revealed a significant difference between the science and mathematics teachers (MD = 18. 93, p <. .001). This is of course very relevant to the context of integrated STEM where teachers are typically trained in a single discipline and the integration of STEM requires them to be able to bring together concepts and practices from across the disciplines. Science teachers may be more inclined to approach integration via experimentation and scientific inquiry, mathematics teachers may be more likely to focus on quantitative reasoning, mathematical modelling and data interpretation. Technology and engineering teachers may bring in other perspectives relating to design, technology use, prototyping and problem solving. The way in which teachers perceive their own professional learning needs may be influenced by these differences, although the present study did not measure the disciplinary processes in any way. Lo (2021) highlighted the importance of well-designed professional development to support teachers in the implementation of integrated STEM and Huang et al. (2022) found that STEM teacher development programs tend to combine active and collaborative approaches to bridge the gap between disciplinary knowledge and classroom practice. These findings provide a useful context in which to interpret the results of the present study: professional development should be designed to help teachers move beyond the teaching of a single subject to collaborative planning and the design of interdisciplinary learning experiences. In practice this would mean that teacher development programs would involve cross- disciplinary teams of science, math, technology and engineering teachers who jointly design STEM lessons around authentic problems. A project around the design of a water filtration system would be an example of such a project, incorporating scientific principles, mathematical measurement, engineering design and technological tools. Such collaborative tasks could help teachers to appreciate the different contributions that the various disciplines can make and to develop a shared approach to the implementation of STEM. That said, as only the science/mathematics comparison is reported in the post hoc table above, any conclusions about differences with regard to the technology and engineering teachers would have to be drawn from the remaining pairwise comparisons.

The one- way ANOVA revealed statistically significant differences in teachers' views of PD across teaching levels, F(3, 56) = 3. 51, p =. .021 (estimated effect size =.). The LSD post hoc analysis showed a significant difference between primary and secondary teachers (MD = 25. 25.02, p =. .003). This suggests that teachers' perceptions of PD for implementing STEM may be different depending on their teaching level. Different levels of teaching will have different pedagogical demands. Primary teachers may require PD to support them in introducing the

ISSN E: 3006-1466
ISSN P: 3006-1458
CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
CJSSR
CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
Vol.04 No.01 (2026)

fundamentals of STEM through play, exploration and age appropriate problem solving. Middle and secondary teachers may need PD to support them in the more advanced aspects of integration such as disciplinary integration, mathematical modelling, scientific investigation and engineering design. Teachers in higher education may require PD that enables them to develop interdisciplinary projects, research informed teaching and the links between STEM and professional practice. These are possible explanations for the differences observed; the data do not actually tell us why the groups were different. Boz (2023) in a systematic review of PD for integrated STEM in primary schools looked at the emerging evidence on how PD can support teachers in the integration of STEM. Lo (2021) also stressed the importance of having systematic design principles for PD in integrated STEM. This literature supports the view that PD should be designed to meet the needs of teachers in their particular context rather than assume that a' one size fits all' approach will work for all. Therefore, PD programs should have a core set of competencies that are common to all, with level specific training on top of that. The core components might be interdisciplinary lesson planning, inquiry based teaching, engineering design, assessment of STEM learning and collaborative problem solving. These could then be tailored to the curriculum, student needs, resources and the nature of the teaching responsibilities at each level. That said, as only the primary/secondary comparison is reported in the post hoc results, further pairwise comparisons are required before any conclusions can be drawn about the differences between the middle and higher study level groups.

The simple linear regression analysis showed a significant model for predicting teachers' professional development (TPD) scores from their STEM education scores, $F(1, 58) = 136.98$, $p < .001$. The model accounted for 70.3% of the variance in TPD scores ($R = .838$, $R^2 = .703$, adjusted $R^2 = .697$). STEM education was a statistically significant positive predictor ($B = 1.235$, $SE = 0.106.106$, $t = 11.704$, $p < .001$). This is the strongest relationship reported in the study and confirms that higher STEM education scores were associated with higher predicted TPD scores. This finding is in line with the literature which has highlighted the importance of including STEM- specific content and pedagogy in teacher professional development. Huang et al. (2022) found that pedagogical knowledge, pedagogical content knowledge and active, collaborative approaches were all key elements of effective STEM teacher development. More recently, Zhou et al. (2023) conducted a meta- analysis of 21 experimental studies involving 1,412 teachers and found that professional development had a positive effect on STEM teachers' self- efficacy ($g = 0.64$, $p < .01$). While self- efficacy is not the same as the TPD construct measured in this study, this evidence does support the value of well- designed professional development for teachers. The regression result also has implications for the design of teacher development programs. PD should not be confined to one- off workshops or the delivery of theoretical content. Teachers should be given the opportunity to work on practical STEM projects, develop interdisciplinary lesson plans, try out different teaching strategies, receive feedback and reflect on their practice. Collaboration between teachers from different disciplines would also be beneficial in the development of integrated approaches. These recommendations are consistent with the literature which identifies active learning, sustained engagement, collaboration and links to classroom practice as key features of effective PD (Huang et al., 2022; Lo, 2021; Zhou et al., 2023). It is important to note that the regression result is evidence of statistical prediction rather than causation. As the study was based on survey data it is not possible to establish that STEM education caused the improvements in TPD. The degree of

ISSN E: 3006-1466
ISSN P: 3006-1458
CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
CJSSR
CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
Vol.04 No.01 (2026)

explained variance should also be viewed in the context of the measurement instruments and the degree of conceptual overlap (if any) between the STEM and TPD scales. Future research could use longitudinal designs, pre- and post- training assessments and classroom observations to determine whether STEM- focused PD leads to actual improvements in teaching practice.

The findings taken together suggest that teacher development programs for integrated STEM should be designed in the context of the teachers' professional lives, taking account of their disciplinary backgrounds and individual learning needs. There is no evidence of a statistically significant gender difference so the data do not support the notion of gender-specific program design. There are, however, significant differences by STEM training status, academic qualification, subject specialism and teaching level which would all merit further investigation when it comes to the design of professional learning. Three key priorities emerge from the data. The first is that professional development should be needs-based and differentiated, with the content of the program adapted to the teachers' subject knowledge and their actual teaching responsibilities. The second is that the programs should focus on practical and collaborative STEM pedagogy, with an emphasis on interdisciplinary projects, inquiry-based learning, engineering design and the opportunity to apply the new approaches in the classroom. The third is that there should be a commitment to sustained professional support in the form of mentoring, peer learning, feedback and follow-up, rather than just one-off training events. These priorities are in line with the findings of recent systematic reviews of STEM teacher professional development and with the research into the relationship between professional development and teacher self-efficacy (Boz, 2023; Huang et al., 2022; Surahman & Wang, 2023; Zhou et al., 2023). The findings should also be viewed in the context of the study's limitations. The sample size was only 60 and some of the subgroups were quite small (in particular the group of teachers with a PhD and the group of primary teachers). The cross-sectional nature of the data precludes any claims of causality and the post hoc results do not include all the pairwise group comparisons. The finding that teachers without any STEM training had a higher mean perception score also requires further investigation before any practical interpretation can be made. Future work would benefit from a larger and more diverse sample, with attention to the content and quality of previous training, validation of the measurement instruments and the integration of survey data with interview data, classroom observations and evaluations of the professional development interventions.

Conclusion

The study looked at the professional development of STEM teachers in terms of differences by gender, prior STEM training and education, teaching level and specialization and the predictive relationship with the STEM-related scores and professional development. It found that the professional development experiences and perceptions of teachers are as diverse as their own educational and professional learning experiences in different subjects and teaching contexts. The results did, however, indicate that variability should be considered in the context of the teachers involved and the instruments used in the study. There was no significant difference in the professional development experiences and perceptions of male and female teachers, suggesting that gender did not have an impact on the professional development of the teachers in the study. The results of the teachers' prior STEM training did have a significant impact. Interestingly, the teachers without any STEM training actually had a higher mean score than

ISSN E: 3006-1466
ISSN P: 3006-1458
CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
CJSSR
CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
Vol.04 No.01 (2026)

their trained counterparts. This may point to a gap in the relevance and quality of the available STEM training. The mean scores also showed significant differences according to the teachers' academic qualification, specialization and teaching level. This would suggest that the professional development needs of teachers are not all the same. The regression analysis showed that the STEM predictor had a positive and significant relationship with teachers' professional development and that the model accounted for 70.3% of the variance in the outcome. As the study was based on observational data, the relationship should be interpreted as predictive rather than causal. In summary the study suggests that for the effective and sustainable implementation of STEM education in schools and school systems a well-designed, context sensitive and practice based professional development program for teachers over time is required. Future research should be aimed at determining the effects of different professional development models (longitudinal or intervention based research) and/or different samples of teachers on different (larger and more diverse) professional development models.

Recommendations

The recommendations for teacher development set out below are drawn from the study findings as are the recommendations for schools and for policymakers.

- The fact that 68.3% of teachers reported having no STEM training at all points to huge gaps in structured STEM professional learning. It is absolutely essential that both education and teacher training departments provide professional learning that is focused on interdisciplinary lesson planning, inquiry and problem based learning, project based learning and the use of a range of technologies in the classroom. In the context of STEM professional learning, particular attention should be paid to those teachers who have not previously had any such training.
- The higher average professional development score of the teachers with no prior STEM training warrants further investigation. PD programs should be evaluated on the relevance and quality of the training and on the extent to which participants are able to apply what they have learned in their own classrooms. The programs should give participants the opportunity to engage in a range of classroom activities and STEM projects, to do demonstration teaching, microteaching and to reflect on their teaching in the context of STEM lessons. Ongoing mentoring and supportive classroom visits should be in place to assist with the application of the learning that took place during the PD.
- The differences in terms of academic qualification, subject specialism and level of teaching would suggest that professional development should be differentiated to meet the needs of the various groups of teachers. It is vital to assess the level of prior knowledge and skills of the teacher prior to any PD intervention in order to ensure that the activities are appropriate for that teacher. For instance, it may be sufficient to develop the basic skills of teaching STEM integration for those teachers who are new to teaching STEM in an integrated way, whereas for more experienced teachers the PD might focus on developing their expertise in other teaching and learning strategies (e.g. assessment, project based learning etc). It is essential to have a clear understanding of the different levels of subject specialism and of teaching before you can develop appropriate interventions for the various groups of teachers.
- It will be important for future work to look at public and private institutions in a range of geographic locations in order to improve the generalizability of the studies. Intervention

based and longitudinal studies are required to determine the impact of different models of professional development on the improvement and sustainability of teaching practice.

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CJSSR
CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
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