Designing a teacher development programme for improving the content knowledge of grade 12 mathematics and science teachers

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This paper profiles a community engaged initiative that is in a form of a teacher development programme (TDP) offered by the Institute for Science and Technology Education (ISTE). The programme sought to improve grade 12 mathematics and science teachers' content knowledge. The ISTE TDP adopts an iterative approach where feedback from participating teachers informed the planning and design of the following year's edition. ISTE TDP is based on the teachers' needs; conducted by facilitators who are significantly versed in the teaching and learning conditions in schools; has interactive sessions that are largely participant-centred; and takes place over 5days of 8hours each. The benefit of ISTE TDP is a capacitated community of teachers with more confidence and enthusiasm.

Key words: teacher development models; community engagement; teacher needs

Introduction

Prior to the inception of democracy in South Africa the education system was designed along racial lines. The black population was offered a sub-quality, under-funded and under-resourced education that was largely underpinned by the principles and philosophy of fundamental pedagogy, which prescribes control, authoritarianism and 'top-down' instructional approach. In particular, it was a form of education that consolidated the idea of sub-quality, subordination and inferiority. Furthermore, as mentioned by the Department of Education (2007:4), a considerable number of active teachers received their pre-service education and training (PRESET) prior to the era of democracy. It is argued that the PRESET offered to the teachers was inadequate as it was intended to perpetuate the aims and purpose of apartheid. Thus, the teachers' content knowledge (TCK) is, arguably, inherent from the apartheid education and this renders it insufficient and irrelevant for the current school curriculum. Drawing on Shulman (1986) work on teacher knowledge, teacher content knowledge refers to the knowledge of facts, concepts, procedures and principles of either mathematics and science.

Post-apartheid era has been characterized by a number of school curriculum changes and teacher development programmes intended to reverse the legacy of apartheid education and address the educational needs of a democratic society. The changes in the curricula in South Africa have created challenges for teachers that range from inadequate content knowledge (Department of Education, 2007; Taylor, 2011) to inappropriate and ineffective instructional methods (Department of Education, 2007:4). Even though there is a multiplicity of factors that directly impact on learning, teacher effectiveness is at the crux of learner success. Hence, the link between teacher content knowledge and learner achievement is well documented (see, for example, Baumert, Kunter, Blum, Brunner, Voss, Jordan, Klusmann, Krauss, Neubrand & Tsai, 2010; Tchoshanov, 2011). In South Africa, for example, since 2010 the highest percentage pass in grade 12 learners' results in physical science and

mathematics is 67.4% and 59.1%, respectively (Department of Basic Education, 2013: 10). It is argued that these less pleasing results can be linked to the inadequate TCK, that has been noted by the Department of Education (2007) and Taylor (2011). In addition, Bryan (2011) found that teachers in the Limpopo province, South Africa who lacked subject knowledge resorted to 'excessive use of safe talk, supported by notes on the blackboard, frequent referral to textbooks and extensive use of repetition' (p 136). Evidence attesting to the ineffectiveness of such an instructional approach abounds.

A tool for change will be an initiative that can empower teachers with necessary capacity to manage curricula changes and enhance effectiveness. In turn, teachers, as members of a community, have responsibility to co-operatively take joint action to find and create solutions to learning problems confronting their communities. This paper profiles a community initiative in a form of a teacher development programme (TDP) that sought to improve mathematics and science teachers' content knowledge. It addresses the question: How has the teacher development programme offered by the Institute for Science and Technology Education (ISTE) as a community engaged initiative been designed to improve the grade 12 mathematics and science teachers' content knowledge? ISTE is a research institute at the University of South Africa that renders community engaged oriented programmes to mathematics, science and technology teachers; conducts research; and provides post-graduate education and training in mathematics, science and technology education.

Reflecting on some teacher development programmes

There have been teacher development programmes in South Africa undertaken to empower teachers so that they can manage the demands and challenges posed by the curricula. The respective foci and goals of the programmes were distinct. For example, Onwu and Mogari (2004) focused on familiarising teachers with curriculum changes and improving their content knowledge and classroom practice; the programme by Mogari (2014) introduced grade 12 teachers to a particular instructional approach; the Mpumalanga Secondary Science Initiative (MSSI), was intended to improve the teaching of mathematics and science at junior secondary level in the province of Mpumalanga (Rogan et al. 2002). The Holistic Professional Development Model (HPD) was built on a university non-formal programme intended to improve teachers' physics content knowledge and classroom practice (Kriek & Grayson, 2009) while the Data Informed Practice Improvement Project works with grades 7 – 9 mathematics teachers on understanding and engaging learner errors as a mechanism for teacher learning (Brodie, 2014). Evident in these programmes is the fact that the needs of teachers are presumed because there is no evidence of needs analysis or rather basing a programme on the needs of the participants. In other words, the planning and designing of the teacher development programme was more top-down rather than being bottom-up where there is consultation with the teachers in order to determine their needs for development.

What is also notable about the programmes is the design and approach used in each of them. For example, Onwu and Mogari (2004) adopted a systemic approach and designed their programme concentrically ranging from teachers in the centre to school district manager on the outside. The roles and responsibilities of stake-holders at each level of the spiral were clearly spelt out. The MSSI followed a cascade approach and clustered teachers according to their respective districts. Cluster leaders met periodically for professional development activities with a view to sharing their experiences with their cluster members in their school settings (Jita & Ndlalane 2005: 296). The HPD model used an engaged-participatory approach to optimise the effectiveness of the non-formal programme (Kriek & Grayson, 2009). The HPD model was designed to avail material and conceptual resources to teachers and engaging them through a participatory mode on strategies for adopting, adapting and applying the resources in a teaching context. Even though each of these teacher development programmes tends to follow an approach and use a design that is compatible with its goal(s) and purpose, it is not based on the needs of the teachers.

ISTE Teacher Development Programme

The ISTE TDP is a researched-based teacher-centred model of a community engaged approach that considers the needs and priorities of the community (i.e. mathematics and science teachers) and creates a space to encourage teacher participation. ISTE TDP is offered by facilitators who have been purposefully identified and then attuned to the needs of the teachers and the goals of the program. The programme is evaluated annually and the outcomes thereof serve as basis for the improvements to be effected on the subsequent one. The benefit of the envisaged development programme is a capacitated community of teachers which will hopefully teach better and effectively, and thus bring about meaningful learning.

ISTE TDP aims to empower mathematics and science teachers to be more knowledgeable about aspects of the curriculum. This is done by improving the content knowledge of the teachers. An important question is how can a community engaged initiative that is in a form of a teacher development programme be designed to enhance TCK.

Determining the teachers' needs for ISTE TDP

The teachers' needs were determined using a teacher questionnaire which was triangulated with learner questionnaire and examiner's report. The questionnaires were developed, then scrutinized for face and content validity by established researchers and thereafter piloted. The reliability of the questionnaires was determined by checking whether there was consistency in the responses in the pilot and main studies.

Teacher questionnaire: The teacher questionnaire comprised 12 items of various forms (i.e. yes/no; Likert-type and open-ended questions) that elicited information on their demography, class sizes, topics considered difficult to teach, challenges they experienced in teaching the topics, and their views on possible ways to improve the teaching of the

identified topics. Mathematics, therefore, is used to illustrate how the difficult topics were identified in 2009. Table 1 shows topics teachers considered difficult to teach as well as the respective number of teachers that selected the topics.

Table 1: *Mathematics topics teachers found difficult to teach*

Topic	*No. of teachers (n = 69)*
Financial mathematics	13
Linear programming	16
Analytical and Transformation geometry	12
Trigonometry	7
Probability	13
Statistics & data handling	8

In terms of possible ways to improve TCK, table 2 presents the teachers views.

Table 2: *Teachers' suggestions on ways of improving the teaching of difficult topics*

Teachers' suggestions	*No. of teachers (n =69)*
Content workshop/peer training/in-service training needed	40
Need equipment/apparatus	8
Materials/better text books needed	5
Reduce class size	9
Better teaching of learners at lower grades	4
Maths and Science learners to be selected based on ability	1
Use expert teachers for maths and science	2

Table 2 shows 40 (58%) teachers preferred content workshop/peer training/in-service training as a way to help them improve their knowledge of the identified topics. Furthermore, they stated the topics they considered difficult to teach were not in the curriculum during their pre-service training; hence their knowledge of the topics is limited. The overwhelming choice for content workshops for the professional development of the teachers formed the foundation of the ISTE TDP.

Learner questionnaire: It teased out information on the learner demography, topics they thought were difficult to learn (see Table 3) and reasons for considering the identified topics difficult (Table 4).

Table 3: *Mathematics topics learners found difficult to learn*

Topic	*No of learners (n = 316)*
Financial mathematics	39
Sequence and series	21
Linear programming	38
Trigonometry	103
Functions and algebra	59
Analytical and Transformation geometry	42

Data handling	5
Statistics and probability	9

The table clearly indicates that the top four topics learners find difficult are trigonometry; functions and algebra; analytic and transformation geometry; and financial mathematics. This is not consistent with what teachers found difficult. Table 4 presents reasons learners advanced for finding the topics difficult.

Table 4: *Learner reasons for difficult topics*

Reasons	*No of learners*
Topics are abstract	15
Topics are taught in the afternoon	20
Not enough time is given for the teaching of these topics	103
Lack of appropriate skills and knowledge of such topics and subjects	54
My teachers are too fast in lesson delivery	45
Not adequate learning materials like computers systems for large classes	32
My teachers teach some chosen topics and leaves others to the fate of the learners	49

Notably, the majority of learners clearly indicate that not enough time is given for the teaching of the topics. However this was not mentioned by teachers as a possible way to improve the teaching of the difficult topics (see table 2).

Examiner's report: After the end-of-year Grade 12 learners' examination answer scripts have been scored, the examiner compiles a report based on the analysis of the learners' answers. School district wide meetings of mathematics and science teachers are convened by the respective subject specialists to discuss the report. The developers of the teacher development programme attend the meetings in order to note topics that learners scored poorly in and possible reasons for poor performance in those topics.

Topic selection: The data from three sources (i.e. teacher and learner questionnaires plus examiner's report) were thoroughly considered in order to enable the final selection of mathematics topics to be taught at ISTE TDP. It was however noted that order of preference of topics by learners and teachers was different. For example, 103 learners found trigonometry difficult to learn while 7 teachers had problems with the same topic, and the examiner also identified trigonometry as one of the topics that learners performed poorly particularly in the latter part of the question. He explained reasons for poor performance as follows:

i. Questions 8.1.3 & 81.4: Used a calculator to calculate the values of the angles α *and* β *and proceeded to find the value of the ratio ending up with the decimal. Common errors/misconceptions that occurred are:* $\cos\beta = 180° - \alpha$*;* $\cos\beta = \cos\left(-\frac{15}{17}\right)$*, in 8.1.4 after expanding they substituted with the values of the angles calculated in 8.1.3. The other common mistake in 8.1.4 is in the expansion, where they wrote as follows:* $\sin(\beta - \alpha) = \sin\alpha\cos\beta - \cos\alpha\sin\beta$

ii. *Question 8.2.1: Most candidates experienced problems with the co-functions, for example, wrote* $\sin 2x = \sin(90° - 2x)$ *or* $\cos 2x = \cos(90° - 2x)$. *Many candidates missed the bracket and* $-\cos 2x = -1 - 2\sin^2 x$, *division was not following the rules but cancelled in order to end up with tan x , for example,* $\frac{1-1-2\sin^2 x - \sin x}{2\sin x \cos x} = \frac{-2\sin^2 x}{2\cos x}$.

iii. Question 8.2.2: Many candidates expanded correctly and divided by cos x (forgetting that it could be zero)
(Chauke, 2010)

Noting that trigonometry has always been in the curriculum and teachers were not coming across it when they had to teach it and also the fact that teachers are provided with continual support and coaching by the subject facilitators, it was decided not to include it in ISTE TDP. Instead the focus was on topics that were recently introduced in the curriculum and teachers, learners and examiner considered problematic. Thus, financial mathematics; linear programming; probability, statistics and data handling and transformation geometry were topics that were taught to teachers in ISTE TDP.

Identification and training of facilitators and material development

Key requirements for one to be a facilitator in ITSE TDP was to have, among others, 'knowledge of how teachers think about content' (Loucks-Horsley, 2010: 73), sound content knowledge, rich classroom experience and knowledge of learning difficulties and conceptual barriers usually experienced by learners. Therefore, these qualities informed the track record that was used to identify the facilitators.

Once identified the facilitators were then subjected to a one day training workshop to familiarise them with the goals and purpose of ISTE TDP; to spell out the outline and facets of the programme; to discuss with them on how to develop support materials and what support materials to develop for use in the programme; and to ascertain that they are familiar with the principles and process of adult learning. It is mentioned in Loucks-Horsley et al. (2010: 73) that to optimise teacher learning the relevance of content being taught has to be obvious and evident; the taught content has to relate to their real contexts; and teachers should be given ample time to connect new ideas to their background. Loucks-Horsley et al. emphasize that facilitators should be able to engage adult learners in activating their prior knowledge and setting goals for their own learning (p 73). Noting that teacher learning is based on the principles of andragogy while learner learning is underpinned by the principles of pedagogy. It is therefore crucially important that facilitators of teacher development programme have to be aware of the fundamental differences between teaching adults (i.e. teachers) and teaching learners.
After training, the facilitators developed support materials and handed them in to the TDP developers for vetting. This was to ascertain that the materials were in line with the goals and purpose of the programme and would indeed support teacher learning. The support materials were based on the aspects of the curriculum that were identified as problematic to

teach and learn. This contrasts the material selection process followed in school districts in the United States of America Louckes-Horsley et al (2010: 240) noted.

Duration and sessions of ISTE TDP

In order for a teacher development programme to be effective it has to happen over a considerable time so that it's activities can have impact by providing opportunities for in-depth discussion of content, development of conceptions and identification of misconceptions (Garet et al, 2001). Desimone et al (2002: 82) note studies that have highlighted a relationship between the intensity and duration of teacher development programmes and the degree of teacher change. The programme ran over 5 days where each day consisted of 8hours. For mathematics, for example, each day was dedicated to a particular aspect. Given the purpose and goal of the programme, the 5-day duration was sufficient. All sessions were largely interactive and participant-centred. For example, in a mathematics class, a facilitator would spend 5 to 8 minutes introducing and explaining a concept on the board. The teachers then individually work through a worksheet for a specified period. Thereafter, a whole class discussion led by the facilitator on possible ways to solve the given set of problems; possible misconceptions and difficulties learners may encounter learning of the concept; possible to pre-empt and anticipate misconceptions and learning difficulties; and ways to teach the concept would ensue. Whatever is mooted by any of the teachers, the facilitator would write down on the board and then encourages the class to critically analyse and delve into it. This teaching approach promotes active learning, collective participation and coherence (Desimone, et al. 2002). Garet et al (2001) indicate that such an approach makes a teacher development programme effective. The approach was also in line with the social cognitive learning theory that emphasises much of human learning occurring in a social environment (Bandura, 1996). According to the theory learning occurs by observing and interacting with others plus what is also around you.

In science for example, the activities were aligned to help teachers use curriculum materials such as science equipment and technology. The use of science equipment is a curriculum requirement and during the workshop session's provision was made for the individual teachers to share strategies. The teachers were also to share the worksheets they were to use in the classes when they returned to their schools. Furthermore they were also introduced to the use of technology to teach science. According to Dede (2000), technology can be used to reinforce student learning. Bruce and Levin (2001) and Bransford, Brown and Cocking (2000) can be used effectively as a cognitive tool for teaching and learning in the classroom. The 5 day program was developed in such a way that each activity was built on the preceding activities and was followed by more advanced work. Garet et al (2002) support the idea of having coherence and interrelatedness between the various activities, and individual activities need to form part of a coherent programme of teacher learning and development.

Feedback

At the end of ISTE TDP, the teachers completed a workshop evaluation questionnaire. The essence of the evaluation was to determine points of successes, failure (if any) and areas that need improvement for the future. The teachers evaluated the programme as follows:
Table 5 presents teachers' views about the extent to which the set learning outcomes of ISTE TDP were met.

Table 5: *Responses to Evaluation Questions on Learning Outcomes*

Options	*No of responses*	*%*
Completely well	26	49.1
Pretty well	24	45.28
Fairly well	3	5.66
Not very well	0	0
Not at all	0	0
Total	53	100

The table shows that there was no teacher who did not think the stated learning outcomes of the programme were not well achieved. Table 6, however, determines the teachers' views about the way the content and aspects of curriculum were covered.

Table 6: *Responses to Evaluation Questions on Learning Content and Curriculum Coverage*

Options	*No of responses*	*%*
Too advanced	19	35.85
Exactly right	31	58.49
Too elementary	0	0
No response	3	5.66
Total	53	100

Table 6 shows that 94.34% of teachers were positive about the way content and aspects of curriculum were covered. Table 7 shows teachers' views about the relevance of content.

Table 7: *Responses to Evaluation Questions on the Relevance of Content Covered*

Options	*No of responses*	*%*
All relevant	49	92.45
Majority relevant	3	5.66
Not really relevant	0	0
Not sure	0	0
No response	1	1.89
Total	53	100

According to Table 7, slightly over 98% of teachers considered the content relevant to their teaching requirements and needs at school. It is a strong pointer to the prudence of designers in packaging the ISTE TDP in terms of materials and resources. Table 8 is about teachers' views about the duration of ISTE TDP.

Table 8: *Duration of the teacher development programme*

Options	*No of responses*	*%*
Too long	5	9.43
Exactly right	35	66.04
Too short	12	22.64
No response	1	1.89
Total	53	100

Five teachers (about 9.43%) felt the programme was 'too long', 35 (about 66.04%) opined that the programme was 'exactly right' and 12 (about 22.64%) teachers thought it was 'too short'. Table 9 presents how the teachers thought of the pace of facilitators.

Table 9: *Pace of Facilitators*

Options	*No of responses*	*%*
Too slow	1	1.89
Too fast	0	0
Just right	26	49.06
Acceptable	24	45.28
No response	1	1.89
Total	53	100

The table shows that 50 (about 94.34%) teachers did not have problems with the pace of facilitators and its one teacher who the pace was slow. Table 10 presents teachers' views about the activities of ISTE TDP.

Table 10: *ISTE TDPs Activities*

Options	*No of responses*	*%*
Relevant	30	56.6
Interesting	21	39.62
Challenging	0	0
Unsatisfactory	0	0
No response	2	3.77
Total	53	100

The table shows that 51 (96.22%) teachers are satisfied with the activities of the programme. Table 11 provides teachers' views about group dynamics and interactions of ISTE TDP.

Table 11: *Group Dynamics and Interactions*

Options	*No of responses*	*%*
Adequate	30	56.6
Effective	22	41.51
Average	1	1.89
Unsatisfactory	0	0
Total	53	100

The table indicates that all teachers were positive with the group dynamics and interactions of the programme.

Discussions

It is evident from the data that ISTE TDP had a positive impact on the teachers. Probably, what made the programme to have the impact is the way it was structured and worked. ISTE TDP is circular, dynamic and functions flexibly and consists of the following interactive, iterative and incremental steps: (1) needs analyses; (2) material and intellectual resource provision; and (3) more knowledgeable community (see Figure 1).

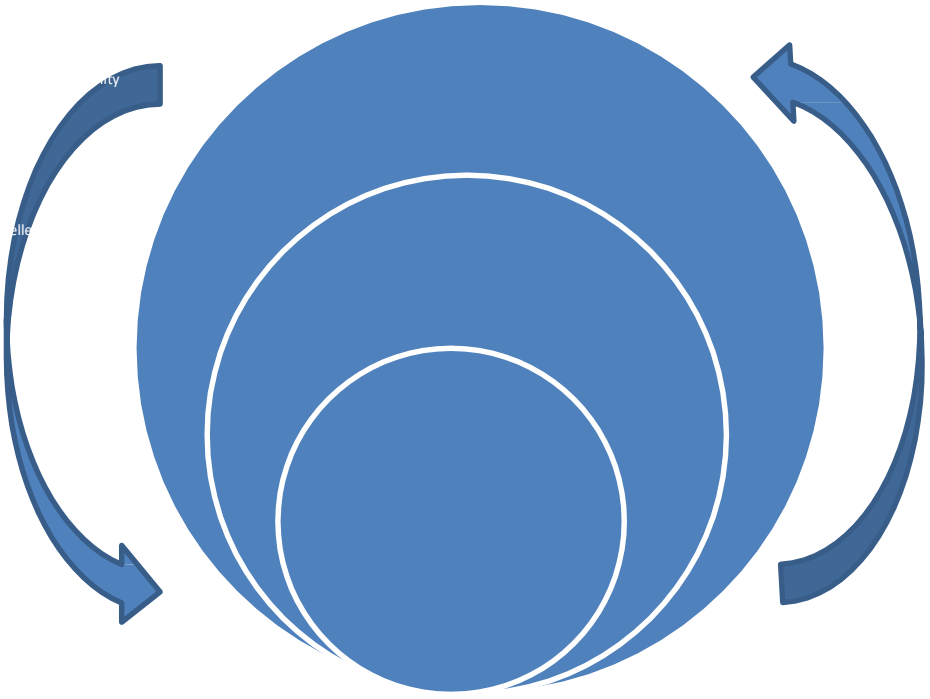

Figure 1: *A structure of ISTE TDP*

In order to improve successfully the content knowledge of teachers, it was essential to first determine the teachers' deficiencies and weaknesses. Hence, the innermost circle depicting needs analysis. In the next step, a teacher development programme based on the teachers' needs was then designed to offer intellectual and material resources. The outcome of the programme was a more knowledgeable community of teachers who can teach better and effectively. The steps of programme are interlinked, interdependent and are not mutually exclusive. The design and approach of ISTE TDP is in line with a framework for designing a teacher development programme provided by Loucks-Horsely et al (2010).

The data show that the teachers' needs and teaching and learning inadequacies were determined through teacher and learner questionnaires and by scrutinising the examiners' reports. Determining the teachers' needs was crucial in designing and shaping a desirable and effective teacher development programme because teacher learning happens better especially if a teacher is taught what she/he wants to learn. According to Harlow (2014) target-minded learning increases the chances for successful learning. Harlow refers to target-minded learning as 'knowing what one seeks from a learning context' (134). Therefore, the content of ISTE TDP was relevant and was based on what the teachers teach in their classes. In particular the programme sought to update and deepen the content knowledge of the teachers. Feedback about ISTE TDP shows that the teachers were content with what they were taught. This tends to enhance the teachers' confidence in their ability and skills to teach better (Onwu & Mogari, 2004; Kriek & Grayson, 2009). By determining the needs of teachers at the onset helps avoid imposing on teachers what might have been irrelevant to them as well as ensures that ISTE TDP directly benefits and empowers the teachers.

Even though there have been efforts to provide teachers with the necessary knowledge and skills to manage the demands and expectations of the curricula changes (see, for example, Onwu & Mogari, 2004; Bantwini, 2009; Bryan, 2011), the current study shows that there are teachers with limited understanding of newly introduced topics in the curricula. Perhaps, the type and objectives of various teacher development programmes on offer need close scrutiny particularly that the data show that teachers need more training. The need for training is consistent with a finding by Bryan (2011). Based on this observation it is claimed that the need for teacher development programme is not always the brainchild of the authorities or education officials.

What is also evident is that what teachers consider difficult to teach, learners don't necessarily deem it a challenge to learn and vice versa. Possibly the discrepancy, as it is posited, could be due to the fact that learners are much more obsessed with passing examinations/tests and are thus always desperate for help on those aspects of the curriculum they feel inadequate, while the teachers' concern is more on enhancing effectiveness and becoming more competent. Moreover, there have been changes in the curricula that have

placed new demands on teachers, and as Guskey (2003) states, there is overwhelming evidence showing that teacher development initiatives are essential for making improvements and enabling teachers meet the changing educational demands. Perhaps, it is for this reason there was a sizeable number of teachers (about 58%) who made a call for more training to be organised for them.

It is evident from the data that the participants felt positive about the training methods used, facilitation process followed, activities of the ISTE TDP and group dynamics and interactions that took place during the sessions of the programmes. It may possibly be because of the fact that the facilitators used were familiar with the actual teaching and learning settings found in the participating teachers' schools as well as the curricula teachers need to deliver. As Loucks-Horsley et al (2010: 73) point out, it is paramount that facilitators of teacher development programme know and understand the actual teaching and learning setting in schools. Anderson, Rourke, Garrison and Archer (2001: 2) indicate that such a calibre of facilitators can design and organise appropriate learning experiences, use relevant activities, facilitate beneficial participant-participant discourse, encourage co-operative and interactive learning, and scaffold learning experiences through direct institution. Harlow (2014: 120) supports, understanding what participating teachers learn and use in their teaching is important to developing appropriate instruction. Thus, it is advisable to use facilitators with profound knowledge of the participating teachers' school settings because they can plan and design an appropriate teacher development programme that can optimise teacher learning. It is also important to note that un-interesting and irrelevant activities used in a teaching and learning setting can de-motivate participants and make them hate either the subject or facilitator; or both.

In conclusion, the study highlights key issues to consider when designing and shaping a teacher development programme. Firstly, it is important to determine the teachers' needs and use the findings to design and shape an in-service programme for them. By so doing the programme tends to address what the teachers want to be helped with, thus rendering the programme effective. Secondly, even though there have been concerns raised about the importance of a teacher development programme being of long duration, the current study shows that the issue of duration should be informed by the goal and purpose of the programme. Thirdly, when identifying facilitators for a teacher development programme it is advisable to go for people who are considerably knowledgeable about the actual teaching and learning settings and curriculum offered. Lastly, a teacher development programme should have interlinked, dynamic and iterative steps, as this enhances relevance and effectiveness. It should however be mentioned that further data on classroom visits is required to consider ISTE TDP effective.

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