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Modelling teachers' self-directed learning and engagement in a STEAM-based professional development program: A structural equation modelling study in South Africa

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Abstract

Teacher professional development in South Africa increasingly occurs through short learning programs (SLPs), yet little is known about how teachers' self-directed learning (SDL) capacities dynamically interact to support engagement within such compressed professional learning contexts. While prior studies have examined SDL domains largely as linear or intrapersonal constructs, fewer have modeled their mediated and relational interplay, particularly in short-duration, practice-oriented programs. This study investigated how four domains of teachers' perceived SDL abilities, motivation, planning and implementation, self-monitoring, and interpersonal communication, directly and indirectly influence engagement in a STEAM-oriented SLP for in-service physical sciences teachers. Using a convergent embedded mixed-methods design, quantitative data were collected through the self-directed learning instrument at the end of the program, complemented by interviews and observations. Exploratory and confirmatory factor analyses supported the four-domain SDL structure, and structural equation modelling (SEM) was employed to test hypothesized causal pathways. The findings revealed that motivation influenced engagement both directly ($\beta = .18$, $p < .05$) and indirectly through planning and implementation (indirect $\beta = .27$, total $\beta = .45$), while self-monitoring affected engagement primarily via interpersonal communication. Planning and implementation emerged as the strongest direct predictor of engagement ($\beta = .46$, $p < .01$). The model demonstrated acceptable fit indices (CMIN/DF = 2.12, CFI = .94, TLI = .91; RMSEA = .07). These results suggest that SDL in SLPs operates as a relational and mediated process rather than a purely individual capacity. The study contributes theoretically by reconceptualizing SDL as a systemic construct and methodologically by demonstrating the value of SEM for modelling complex learning dynamics in short professional development interventions.

Keywords: self-directed learning, teacher professional development, short learning program, SEM, STEAM pedagogy

INTRODUCTION

Teacher professional development (TPD) remains a persistent challenge in South Africa, shaped by systemic inequality, resource constraints, and policy-driven expectations that often outpace teachers' lived classroom realities (Bantwini, 2019; Verster et al., 2024). In physical sciences education in particular, teachers are expected to foster creativity, problem-solving, and scientific reasoning, while working within overcrowded classrooms and examination-oriented curricula (Ogunniyi & Iwuanyanwu, 2024; Stott, 2025). These conditions have intensified interest in professional development approaches that extend beyond episodic training events toward forms of learning that cultivate teachers' agency, adaptability, and sustained professional engagement (Colucci-Gray et al., 2019; Ngcoza & Southwood, 2015). Although some progress has been reported (Erduran & Msimanga, 2014), the severity of these challenges, particularly in resource-constrained areas, has limited the success of such

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Contribution to the literature

- This study reconceptualises self-directed learning as a relational and mediated system of interacting domains rather than isolated intrapersonal traits.
- Using Structural Equation Modelling, it demonstrates how motivation and self-monitoring influence teacher engagement indirectly through planning and interpersonal communication in short professional development contexts.
- Using Structural Equation Modelling, it demonstrates how motivation and self-monitoring influence teacher engagement indirectly through planning and interpersonal communication in short professional development contexts.

initiatives in fostering sustained professional agency (de Putter-Smits et al., 2022; Stott & Guthrie, 2025). Globally, TPD discourse has increasingly shifted from externally driven, transmission-oriented models toward approaches that position teachers as active agents of their own learning (Nurhadi et al., 2023; Whitcomb et al., 2009; Warford, 2011). Within this shift, self-directed learning (SDL) has emerged as a cornerstone for sustainable professional growth, emphasizing teachers' capacity to initiate, plan, monitor, and socially negotiate their learning trajectories (De Beer et al., 2018; Verster et al., 2024; Zimmerman, 2016). However, despite the prominence of SDL in policy and theory, its enactment within short-duration professional learning contexts remains insufficiently understood.

Short learning programs (SLPs) have become a prominent mode of TPD delivery in South Africa and other resource-constrained systems (Mafokwane et al., 2024; Stott & Guthrie, 2025). Designed to be intensive, practice-oriented, and time-efficient, SLPs offer important opportunities for professional renewal, yet they also pose a paradox. While they aim to stimulate long-term professional change, their short duration limits sustained support and follow-up. Existing SDL research has identified key domains underpinning SDL, commonly including motivation, planning and implementation, self-monitoring, and interpersonal communication (Cheng et al., 2010). Prior studies have examined relationships among these domains, often through correlational or linear modelling approaches, and predominantly within formal academic or long-term professional settings (Louws et al., 2017; Shen et al., 2014). While this body of work has been instrumental in validating SDL constructs, it has tended to conceptualize SDL as primarily intrapersonal and additive, offering limited insight into how SDL domains interact dynamically and relationally within short, practice-based professional development interventions. To address this conceptual gap, there is a need for an analytic framework that captures SDL not as a set of isolated capacities, but as a system of interrelated processes operating within the constraints of short, practice-based professional learning environments. In the context of SLPs, where time compression intensifies the interdependence between motivation, planning, reflection, and social interaction, understanding how these domains dynamically interact becomes crucial for explaining professional engagement. **Figure 1** therefore presents a theoretically informed structural representation of the hypothesized relationships among key SDL domains and teacher engagement, offering a relational lens through which the complexity of SDL enactment within STEAM-oriented SLPs can be examined.

Structural equation modelling (SEM) offers a methodological and epistemological lens well suited to addressing this limitation. By employing a SEM approach (**Figure 1**), this study tests how SDL domains interact causally, thereby contributing both theoretically and practically to rethinking TPD in South Africa. Unlike approaches that focus on isolated predictors, SEM enables the modelling of mediated and indirect relationships among multiple interdependent constructs, aligning with conceptions of learning as systemic and relational rather than fragmented. From this perspective, SDL can be understood not as a collection of independent traits but as a web of mutually reinforcing processes that unfold through social interaction, planning practices, and reflective engagement. Within STEAM-oriented professional development, these relational dynamics may be particularly salient. Arts-integrated pedagogies foreground collaboration, creativity, and dialogical meaning-making, creating conditions in which interpersonal communication and reflective planning are not peripheral but central to professional engagement (Belbase et al., 2022; Burnard et al., 2021). Yet empirical models capturing how SDL domains operate within STEAM-based SLPs remain scarce, especially in Global South contexts.

In response to these gaps, this study investigates how four domains of teachers' perceived SDL abilities, motivation, planning and implementation, self-monitoring, and interpersonal communication, interact to influence engagement within a STEAM-oriented SLP for in-service physical sciences teachers in South Africa. Rather than treating SDL domains as parallel predictors, the study models their direct and indirect pathways using SEM, complemented by qualitative data to contextualize and explain the observed relationships.

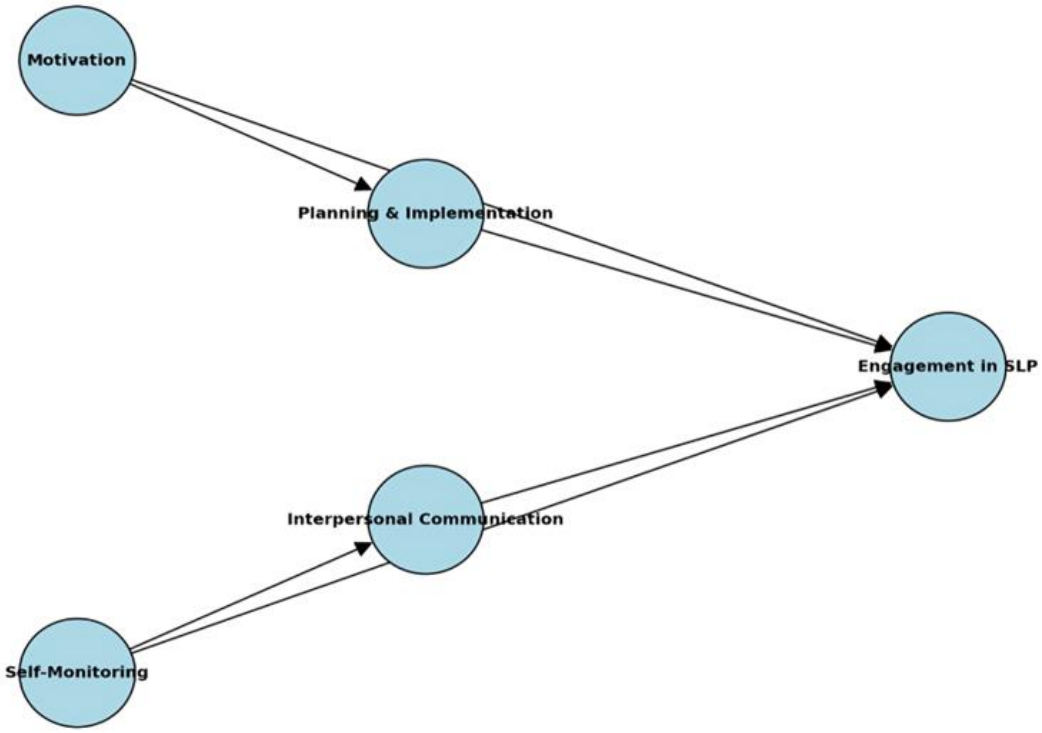

Figure 1. Proposed SEM of SDL domains and engagement (Source: Author's own elaboration)

Purpose of the Study

Focusing on the integration of arts into science teaching, this study tested a structural model to examine how four domains of SDL: motivation, planning, self-monitoring, and interpersonal communication, predict teacher engagement in an SLP. By analyzing the interdependence among these domains, the study measures their direct and indirect effects within networks of TPD. The central research question guiding this study is: *How do the domains of SDL interact, directly and indirectly, to influence teachers' engagement in a STEAM-based SLP?*

By addressing this question, the study contributes theoretically by reconceptualizing SDL as a relational and mediated construct, methodologically by demonstrating the value of SEM for modelling professional learning dynamics in short-duration interventions, and empirically by providing context-sensitive insights into teacher engagement in STEAM-oriented professional development in South Africa.

Theoretical Framework

SDL has long been viewed as the essence of adult education, emphasizing initiative, autonomy, and self-regulation (Knowles, 1975). However, to regard SDL only as a set of technical competencies would be reductive. Philosophically, SDL embodies a tension between individualism and collectivism: while it stresses personal responsibility for learning, it also acknowledges that learning is always embedded in social and cultural contexts (Cheng et al., 2010; De Beer et al., 2018). This tension is particularly salient in teacher development, where professional agency requires not only internal motivation but also relational support through dialogue, mentorship, and collaboration (Ogunniyi & Iwuanyanwu, 2024). SDL also invites a broader epistemological question: *can teachers truly be self-directed in systems where knowledge, assessment, and policy are externally dictated?* Some scholars argue that SDL risks being appropriated as a neoliberal discourse that shifts accountability from institutions to individuals (Louws et al., 2017). Counterarguments suggest that cultivating SDL is not about withdrawal of support but about scaffolding teachers toward greater agency (Bosch, 2017), in line with Vygotsky's (1978) notion of the zone of proximal development (Warford, 2011). This study therefore conceptualizes SDL not as independence from others, but as interdependence mediated through motivation, planning, monitoring, and communication.

Domains of SDL and TPD

The self-directed learning instrument (SDLI) developed by Cheng et al. (2010) identifies four domains, namely, motivation, planning and implementation, self-monitoring, and interpersonal communication. These domains reflect cognitive, affective, and social dimensions that are mutually constitutive. Motivation represents the intrinsic readiness to engage; planning and implementation involve setting goals and mobilizing strategies; self-monitoring entails critical reflection and adaptive regulation; and interpersonal communication captures the collaborative exchange of feedback, dialogue, and co-construction of knowledge.

The domains are not discrete silos but dynamic pathways. They reflect both cognitive and socio-emotional competencies essential for effective TPD (de Putter-Smits et al., 2022). For example, motivation energizes planning, self-monitoring strengthens through peer dialogue, and interpersonal communication often becomes the catalyst for refining planning (Shen et al., 2014). From a philosophical perspective, SDL is often framed as the responsibility of the individual teacher. However, this assumption risks overlooking the relational and contextual factors that enable or constrain learning. Teachers may be highly motivated, yet without supportive structures (Stott, 2025), opportunities for collaboration (Bantwini, 2019), and access to resources (Mafokwane, 2024), their SDL capacity cannot be fully realized (De Beer et al., 2018).

Research emphasizes that effective TPD is collaborative, practice-oriented, and contextually relevant (Erduran & Msimanga, 2014; Steyn, 2011). In South Africa, fostering SDL within TPD is particularly crucial because systemic inequalities limit access to continuous professional learning opportunities (Bantwini, 2019; De Beer et al., 2018; Ngcoza & Southwood, 2015). SDL allows teachers to sustain growth beyond externally provided workshops (Author, 2024). Yet, without systemic support, an overemphasis on SDL risks burdening teachers with unrealistic expectations to fix systemic problems through individual effort (Louws et al., 2017).

SLPs

Bantwini (2019) and Stott (2025) emphasize the catalytic potential of SLPs in advancing teacher development through structured, flexible learning formats. When designed around active pedagogies such as STEAM, they can expand teachers' pedagogical repertoires and stimulate creativity (Mafokwane et al., 2024). As De Beer et al. (2018) argue, the strength of SLPs lies not only in their ability to expose teachers to novel pedagogical strategies but also in their potential to spark reflective, SDL that extends beyond the formal intervention. However, the role of SLPs in sustaining long-term professional development remains contested. Cronje (2015) highlights that their brevity risks limiting transformative impact, especially when teachers face systemic constraints such as overcrowded classrooms, inadequate resources, and assessment-driven curricula. Stott (2025) contends that SLPs should not be judged solely on duration but on their capacity to function as seedbeds for individual learning activities, which are essential to deepen engagement beyond formal interventions. Considering both the former and the latter views in the current study, then, SLPs must be understood less as finite events and more as spaces of possibility where teachers activate latent capacities for autonomy, collaboration, and creativity. When situated within a broader ecology of professional learning, SLPs can offer both immediate pedagogical enrichment and long-term professional empowerment (Erduran & Msimanga, 2014; de Putter-Smits et al., 2022). This study therefore situates the SLP not merely as an event but as a testing ground for how SDL domains operate in practice.

SEM in TPD Research

SEM provides a methodological tool for testing the causal interplay between latent constructs, offering insights into both direct and indirect pathways (Kline, 2016). In this study, SEM was not only a statistical technique but also a theoretical choice: it aligns with the assumption that SDL is systemic rather than linear, relational rather than atomistic (Collier, 2020). By modelling interactions between motivation, planning, self-monitoring, and interpersonal communication, SEM provides empirical grounding for the philosophical claim that SDL is an ecology of interdependent abilities rather than a sum of parts. At the same time, SEM is not without limitations. While it affords causal inference and statistical precision (Collier, 2020), it risks reducing dynamic teacher experiences to abstracted pathways and coefficients. Professional learning is not merely a statistical artefact but a lived process embedded in social, cultural, and material realities (Mafokwane et al., 2024). Relying exclusively on SEM could obscure these contextual dimensions. This study therefore complemented SEM with qualitative evidence; interviews, classroom observations, and artefact analyses to ensure that structural patterns were interpreted in light of teachers lived enactments.

METHODOLOGY

This study adopted a convergent embedded mixed-methods design (Creswell & Creswell, 2022), with quantitative analysis constituting the dominant strand and qualitative data serving an explanatory and contextualizing function. This design was selected to align with the study's epistemological positioning, which conceptualizes SDL not as a purely individual attribute but as a relational and situated process that unfolds within specific professional learning environments (Warford, 2011). SEM was employed as the principal analytic approach to examine the direct and indirect relationships among SDL domains and teacher engagement. Qualitative data were embedded to illuminate how these relationships manifested in practice within an SLP, thereby mitigating the risk of treating statistical associations as decontextualized abstractions.

Context and Participants

The study was conducted within a STEAM-oriented SLP offered to in-service physical sciences teachers in South Africa. The program was designed to support

interdisciplinary pedagogical innovation through arts-integrated, collaborative, and inquiry-based learning activities. Participation in the program was voluntary. A total of 89 subjects completed both pre- and post-program questionnaires. Participants represented diverse teaching contexts, including urban, peri-urban, and rural schools. This heterogeneity reflects the broader structural conditions under which South African teachers engage in professional development (Ngcoza & Southwood, 2015; Stott, 2025) and reinforces the relevance of examining SDL within constrained and variable educational settings.

Instruments

Two complementary sets of instruments were employed to capture the multidimensional nature of SDL. On the quantitative side, the SDLI (Cheng et al., 2010) is a validated 20-item instrument organized across four domains: motivation, planning and implementation, self-monitoring, and interpersonal communication. For these domains, Shen et al. (2014) reported the following Cronbach's alpha values:

(1) learning motivation (α = .813),

(2) planning and implementation (α = .825),

(3) self-monitoring (α = .759), and

(4) interpersonal communication (α = .755).

The SDLI structure aligns with the theoretical framing of SDL as a holistic construct encompassing cognitive, affective, and socio-communicative dimensions (Cheng et al., 2010). In the current study, the adapted SDLI was administered before and after the SLP to capture shifts in teachers perceived SDL abilities. To balance this structural account with lived perspectives, a qualitative strand was integrated. Teachers who had participated in the SLP volunteered for semi-structured interviews and classroom observations, and their artefacts from both the SLP and subsequent lessons were collected. The interviews conducted (30-45 minutes) after the SLP and following classroom visits, invited teachers to reflect on their learning trajectories, the relevance of the arts-based pedagogy to their practice, and the constraints they encountered. Observations of selected lessons in the weeks following the SLP provided insight into how teachers enacted SDL in their classrooms, focusing on the use of creative strategies, learner engagement, and evidence of reflective adaptation. The collection of artefacts such as lesson plans, group products, and visual materials, offered additional traces of teachers' evolving practices. Together, these qualitative instruments complemented the SDLI by capturing how teachers understood, enacted, and reflected upon SDL in their own contexts.

Implementation of the SLP

The intervention was a three-day SLP designed to integrate arts into science teaching through STEAM pedagogy. Activities were purposefully selected to align with the social constructivist framework underpinning the study. The activities included problem-based tasks, cooperative jigsaw exercises, use of puppetry and De Bono's hats, and collaborative lesson design. In light of this, teachers engaged in:

1. Problem-based tasks, designed to provoke critical inquiry and collaborative problem-solving, reflecting the epistemic practices of science (Abramczyk & Jurkowski, 2020; Hmelo-Silver, 2004).
2. Cooperative jigsaw exercises, which required distributed expertise and mutual interdependence, echoing Vygotsky's (1978) emphasis on dialogic learning.
3. Puppetry and De Bono's thinking hats, which served as artefacts for epistemological border crossing between science and the arts (Brits et al., 2016; De Beer et al., 2018).
4. Collaborative lesson design, where teachers co-created arts-integrated science lessons, embodying the philosophy that knowledge is socially constructed and contextually embedded.

This combination of methods was not incidental but deliberate. It sought to model for teachers what SDL might look like in practice: autonomy blended with collaboration, creativity scaffolded by structure, and reflection mediated through collective dialogue (Conradty & Bogner, 2020). The three-day program focused on integrating arts into science teaching.

Data Collection and Analysis

Data collection was sequenced in two phases. In the quantitative phase, teachers completed the SDLI both before and after the SLP, allowing for assessment of changes in SDL abilities. This provided the explanatory backbone of the study, quantifying shifts in motivation, planning, monitoring, and communication. For the qualitative phase, supplementary data were collected through semi-structured interviews, classroom observations, and artefact analysis (e.g., lesson plans and group products). This was essential to probe the why behind the what: why some teachers demonstrated stronger SDL shifts, why collaboration flourished or faltered, and how contextual factors (such as resource constraints or cultural artefacts) mediated their engagement.

Data analysis proceeded in three stages. First, exploratory factor analysis (EFA) was conducted to examine the underlying factor structure of the SDLI within the study context. Second, confirmatory factor analysis (CFA) was performed to assess model fitness

Table 1. Reliability of the SDLI

Domain	Number of items	Cronbach's alpha
Motivation	6	.82
Planning and implementation	6	.79
Self-monitoring	4	.81
Interpersonal communication	4	.76
Overall scale	20	.84

Note. All domains demonstrated acceptable internal consistency ($\alpha > .70$)

and confirm the four-domain SDL structure. Although EFA and CFA were conducted on the same sample, this approach was theoretically constrained, but analytically relevant (Kline, 2016). EFA was used to confirm the dimensionality of the data, followed by CFA to test the hypothesized four-domain structure. This two-tiered approach underscored the study's epistemological stance that constructs should be empirically grounded rather than assumed. The potential risk of overfitting is acknowledged and addressed in the limitations. Third, SEM was used to test hypothesized pathways among SDL domains and engagement. SEM was selected not merely as a statistical technique but as a modelling approach aligned with the study's relational understanding of learning. Model fit was evaluated using multiple indices, including CMIN/df, CFI, TLI, and RMSEA. Modification indices were considered only when theoretically defensible and conceptually coherent.

Additionally, path analysis and SEM were employed to test hypothesized causal relationships between SDL domains and engagement. The recursive model incorporated selected error term covariances based on modification indices to improve overall model fit. Standard indices (CMIN/df, CFI, TLI, RMSEA) were reported in accordance with established statistical guidelines, while interpretive judgement guided their evaluation. This analytic strategy aligned with the study's philosophical orientation, moving beyond surface-level description toward causal explanation. SEM was chosen not only for its statistical power but also for its conceptual fit with the view of SDL as a systemic, relational construct: a web of interdependent abilities rather than a collection of isolated skills (Collier, 2020).

Qualitative data were analyzed using a focused, deductive thematic approach, guided by Braun and Clarke's (2006) framework and informed by the SDL domains and SEM pathways identified in the quantitative analysis. The purpose of this analysis was not to generate new theory but to provide explanatory depth, illustrating how relational processes such as peer interaction, reflective dialogue, and collaborative planning supported engagement during the SLP. Transcripts, observation notes, and artefacts were first coded inductively to identify emerging patterns and then deductively interpreted through the theoretical lens of SDL and STEAM pedagogy. Themes such as peer collaboration, creative confidence, and systemic constraint emerged strongly, aligning in important ways with the pathways suggested by SEM. For instance, SEM results highlighting the mediating role of interpersonal communication were reinforced by teacher narratives emphasizing the value of collegial dialogue in sustaining reflection and experimentation. To ensure trustworthiness, coding and theme development were cross-checked by two science education specialists.

RESULTS

The SDLI demonstrated satisfactory internal consistency across all domains, with Cronbach's alpha values ranging from .76 to .82 (**Table 1**). The overall reliability for the 20-item scale was .84, exceeding the recommended threshold of .70.

This reliability suggests that the SDLI is a robust measure of teachers' SDL abilities in the South African context. Importantly, these results extend the validation of the SDLI beyond its original cultural setting (Cheng et al., 2010), showing that the four-domain structure is conceptually coherent in resource-constrained environments. This is philosophically significant because it reinforces the idea that SDL, while individually enacted, has universal cognitive and socio-emotional dimensions that transcend context, even as local circumstances shape its enactment (De Beer et al., 2018; Verster et al., 2024). EFA supported the four-factor solution, while CFA confirmed construct validity with acceptable indices ($\chi^2/df = 2.12$; RMSEA = .07). All SDLI domains demonstrated strong internal consistency, with Cronbach's alpha values ranging from .76 (interpersonal communication) to .82 (motivation), and an overall scale reliability of .84. These reliability and validity findings provide a solid foundation for subsequent structural modelling, ensuring confidence in the measurement structure and its applicability to the South African professional development context.

Descriptive Statistics and Correlations

Descriptive statistics revealed relatively high mean (M) scores across all four SDL domains, with self-monitoring (M = 3.90, standard deviation [SD] = 0.39) and motivation (M = 3.85, SD = 0.42) emerging as the strongest domains (**Table 2**). Engagement in the SLP also scored high (M = 4.02, SD = 0.40), suggesting that participants were actively involved in the learning process.

Correlation analysis demonstrated significant positive associations between SDL domains and engagement, particularly between planning and implementation and engagement ($r = .61$, $p < .01$), and motivation and engagement ($r = .54$, $p < .01$). Strong inter-domain correlations were also observed, most notably between motivation and planning and

Table 2. Descriptive statistics and correlations of SDL domains

Variable	M	SD	1	2	3	4	5
1. Motivation	3.85	0.42	-				
2. Planning and implementation	3.72	0.47	.58**	-			
3. Self-monitoring	3.90	0.39	.41*	.49*	-		
4. Interpersonal communication	3.68	0.45	.36	.44*	.52**	-	
5. Engagement in SLP	4.02	0.40	.54**	.61**	.48*	.56**	-

*Note. **p < .01; p < .05; & Engagement was strongly correlated with all four SDL domains, particularly planning and implementation (r = .61) and motivation (r = .54)

Table 3. Model fit indices for SEM

Fit index	Recommended threshold	Obtained value	Interpretation
χ^2/df (CMIN/df)	< 3 (good), < 5 (acceptable)	2.12	Good
CFI	≥ .90 acceptable, ≥ .95 good	.94	Acceptable
TLI	≥ .90 acceptable, ≥ .95 good	.91	Acceptable
RMSEA	≤ .08 acceptable, ≤ .05 good	.07	Acceptable

Note. The hypothesized model demonstrated acceptable fit to the data

Table 4. Standardized direct, indirect, and total effects in SEM

Pathway	Direct effect (β)	Indirect effect (β)	Total effect (β)	Significance
Motivation → planning and implementation	.59	-	.59	p < .01
Planning and implementation → engagement	.46	-	.46	p < .01
Motivation → engagement	.18	.27 (via planning)	.45	p < .05
Self-monitoring → interpersonal communication	.52	-	.52	p < .01
Interpersonal communication → engagement	.33	-	.33	p < .05
Self-monitoring → engagement	.21	.17 (via interpersonal)	.38	p < .05

Note. Motivation exerted both direct and indirect effects on engagement. Self-monitoring influenced engagement directly and through interpersonal communication

implementation (r = .58, p < .01), and between self-monitoring and interpersonal communication (r = .52, p < .01). These results indicate that SDL is not fragmented into isolated skills but manifests as an interconnected system of abilities. Teachers who reported higher intrinsic motivation were more likely to engage in deliberate planning and strategic implementation, echoing Desimone's (2009) claim that active engagement is driven by underlying motivation. Similarly, the strong correlation between self-monitoring and interpersonal communication supports the argument that reflection is not an isolated cognitive act but one enriched by dialogue and peer interaction (Whitcomb et al., 2009; Bosch, 2017). In practice, this suggests that fostering SDL in professional development must balance individual goal-setting with opportunities for collaborative reflection.

Path Analysis (SEM)

The hypothesized structural model demonstrated good overall fit, with values within the recommended thresholds (χ^2/df = 2.12; CFI = .94; TLI = .91; RMSEA = .07) (**Table 3**). This confirms that the model adequately represents the relationships among SDL domains and teacher engagement.

Table 4 presents the standardized direct, indirect, and total effects. The results revealed several key findings. Motivation significantly predicted teachers' planning and implementation (β = .59, p < .01), positioning it as a strong antecedent of strategic learning behaviors. Planning and implementation, in turn, had a direct and substantial effect on engagement (β = .46, p < .01), indicating that when teachers translated their motivation into deliberate goal-setting and action, they became more meaningfully involved in the SLP. Motivation also influenced engagement directly (β = .18, p < .05), but its indirect effect through planning (.27) produced a stronger overall pathway (total β = .45). Self-monitoring was found to be a powerful driver of engagement, exerting both a direct influence (β = .21, p < .05) and an indirect one via interpersonal communication (indirect β = .17, total β = .38). The link between self-monitoring and interpersonal communication (β = .52, p < .01) highlighted the social dimension of reflective practice, while interpersonal communication itself emerged as a significant predictor of engagement (β = .33, p < .05). Together, these pathways confirm that SDL domains interact in systemic and mutually reinforcing ways to shape teacher learning.

The results presented so far have adequately addressed the first research question: *How do the four domains of SDL interact in predicting teachers' engagement in an SLP?* Evidence from **Table 1** to **Table 4** confirms that motivation and planning play central roles in driving engagement. Motivation influenced engagement both directly and indirectly through planning,

Table 5. Integration of SEM pathways with qualitative evidence

SEM pathway	Quantitative finding	Supporting teacher voice	Classroom observation evidence	Interpretive insight
Motivation → planning and implementation	Motivation strongly predicted planning (β = .59, p < .01).	*"I realized I can plan my lessons independently … before, I always looked for guidelines, but now I know I can create my own activities."* (interview 2)	Teachers who had previously relied on rote notes developed lesson artefacts integrating drawings and posters.	Motivation needs structured scaffolds to translate into deliberate action.
Planning and implementation → engagement	Planning had a strong direct effect on engagement (β = .46, p < .01).	*"Once I designed the drama activity, I saw my learners were excited and I became more committed to using these ideas."* (interview 5)	ST7 used dramatization of photoelectric effect, leading to high learner participation.	Engagement is sustained when planning translates into interactive classroom practices.
Motivation → engagement (indirect via planning)	Indirect effect (.27), stronger than direct (.18).	*"When I saw other teachers' plans, it motivated me to try in my own lessons."* (interview 3)	Group-designed lesson posters demonstrated peer-inspired motivation.	Motivation alone is insufficient; planning mediates its effect on meaningful engagement.
Self-monitoring → interpersonal communication	Strong effect (β = .52, p < .01).	*"Working with colleagues gave me courage … I reflected on my own practice and thought, 'I can do this differently.'"* (interview 3)	Peer feedback sessions during SLP led teachers to adjust lesson strategies in real time.	Reflection gains strength when dialogically shared with peers.
Interpersonal communication → engagement	Significant predictor (β = .33, p < .05).	*"Discussing ideas with others showed me that I'm not alone in these challenges. It made me want to try more."* (interview 1)	ST2's collaborative art-poster lesson generated lively peer-to-peer interaction.	Engagement flourishes when communication fosters collective ownership of ideas.
Self-monitoring → engagement (direct and indirect via interpersonal communication)	Total effect (.38).	*"After teaching with arts, I thought critically about what worked and asked my learners how they felt – it made me improve."* (interview 4)	ST12 refined her energy lesson after reflecting on learners' feedback.	Reflection fuels engagement directly but is amplified by collaborative communication.

Note. ST: Science teacher

underscoring the need for structured scaffolds that translate intrinsic drive into deliberate pedagogical strategies. Self-monitoring, meanwhile, emerged as both a direct and indirect predictor, its effect mediated through interpersonal communication. These results affirm the systemic nature of SDL: reflection gains power when embedded in dialogic exchange with peers. Interview data corroborated these structural pathways. For instance, one teacher reflected:

> I realized I can plan my lessons independently… before, I always looked for guidelines, but now I know I can create my own activities (interview 2).

This illustrates the indirect pathway where motivation, supported by structured SLP activities, translated into deliberate planning and increased engagement. Similarly, another teacher noted:

> Working with colleagues during the SLP gave me courage. When I saw their ideas, I reflected on my own practice and thought, 'I can do this differently' (interview 3).

This reinforces the SEM results that self-monitoring is not a solitary act but is amplified by interpersonal communication. Classroom observations confirmed these insights: teachers who initially defaulted to chalk-and-talk methods began experimenting with creative strategies, such as using role-play to demonstrate the photoelectric effect or visual artefacts to represent energy transfer. Such practices demonstrated the convergence of motivation, planning, and reflection into observable professional engagement. **Table 5** presents the integration of quantitative pathways with qualitative evidence from teacher interviews and classroom observations. By mapping the SEM pathways against teacher testimonies and observed classroom practices. The juxtaposition demonstrates that statistical relationships, such as the indirect effect of motivation through planning, or the mediating role of interpersonal communication were vividly enacted in teachers' professional experiences. For example, the pathway from self-monitoring to engagement was substantiated by teachers' reflections on how peer dialogue sharpened their lesson planning, while classroom vignettes confirmed that creative arts-based strategies emerged

from these reflective conversations. By aligning structural patterns with lived enactments, the results presented in **Table 5** illustrate that SDL is not an abstract attribute but a systemic ecology of interdependent domains shaped by both individual agency and collaborative contexts.

DISCUSSION

The purpose of this study was to examine how domains of SDL interact to influence teacher engagement within a STEAM-oriented SLP. Rather than interpreting the findings as evidence of abstract dispositions, the discussion situates the results within the concrete relational and organizational dynamics of short-duration professional learning. The SEM results indicate that planning and implementation emerged as the strongest direct predictor of engagement. This finding suggests that teachers' engagement in SLPs is less dependent on motivation alone than on their capacity to translate motivation into actionable learning strategies within social and dialogical environments (e.g., De Beer et al., 2018; Iwuanyanwu, 2023b; Louws et al., 2017). It refines existing theories by demonstrating empirically that motivation and reflection achieve pedagogical force only when channeled through planning and interpersonal communication (Chen et al., 2010; Shen et al., 2014). In compressed professional learning contexts, where time and institutional support are limited, structured planning appears to function as a critical mechanism that enables teachers to sustain engagement beyond initial enthusiasm.

The present SEM results strengthen that conclusion: motivation predicted engagement both directly and indirectly through planning and implementation, mirroring Stott (2025) observation that teacher professional learning is strongest where enthusiasm is converted into deliberate instructional design. Motivation exerted both direct and indirect effects on engagement, with its strongest influence mediated through planning and implementation. This mediated relationship challenges linear models of SDL that position motivation as a sufficient driver of professional learning. Instead, the findings indicate that motivation becomes consequential only when embedded within organizational and relational processes that support purposeful action.

Self-monitoring did not directly predict engagement but operated indirectly through interpersonal communication. This pathway highlights the social character of reflective practice in professional learning contexts. Teachers' capacity to evaluate their learning gains appears to be activated through dialogue, peer feedback, and collaborative sense-making rather than through isolated introspection. This finding aligns with sociocultural perspectives on professional learning while remaining grounded in empirically observable pathways. Importantly, the discussion does not claim causal generalizability beyond the study context. SEM pathways are interpreted as relational tendencies within a specific SLP design rather than universal laws of teacher learning. Qualitative data further support this interpretation by illustrating how engagement emerged through collaborative activities, facilitated dialogue, and shared planning opportunities embedded within the program structure.

Furthermore, the reliability of the four-factor SDLI obtained here ($\alpha = .84$ overall) parallels results reported in Cheng et al. (2010) and confirms, within a South African STEAM context, that the SDLI's domains remain robust. The finding that interpersonal communication mediates the effect of self-monitoring on engagement aligns with Whitcomb et al. (2009), who demonstrated that collegial dialogue serves as a catalyst for translating reflective awareness into action. Notably, the pattern of indirect effects observed in this study differs from the more linear trajectories reported by Conradty and Bogner (2020), where creativity and motivation acted as parallel predictors rather than sequential ones. The present study indicates that motivation alone does not guarantee engagement; only when supported by systematic planning does it lead to substantive pedagogical enactment. This divergence underscores the contextual sensitivity of SDL processes and highlights the importance of SLP design features, explicit planning templates, peer feedback loops, and artefact creation, that transform intention into practice (Cronjé, 2015).

Taken together, the findings from the present study suggest that SDL in short professional development interventions should be understood as a situated and mediated process, activated through social interaction and structured learning design. This interpretation avoids idealizing SDL as an individualized capacity and instead positions it as a professional capability shaped by context, pedagogy, and relational affordances. These findings empirically echo Warford's (2011) extension of Vygotsky's (1978) zone of proximal teacher development (ZPTD), which posits that teachers' higher-order capacities emerge through scaffolded participation in professional communities. The SEM pathway linking self-monitoring and interpersonal communication validates this social-constructivist lens: reflective practice gains transformative force only within dialogical interaction (Iwuanyanwu, 2023b). Furthermore, the qualitative evidence of teachers' engagement in arts-infused activities; puppetry, drama, and artefact design illustrates what Freire (1972) described as *praxis*: reflection and action directed toward transformation. The results thus substantiate the Freirean claim that authentic autonomy is achieved through dialogical encounter and critical consciousness, not through isolation. At the same time, the study expands the constructivist framing advanced by Schreiber and Valle (2013), who conceptualized

generative learning as a cycle of prediction, testing, and reinterpretation. The SLP's emphasis on teachers designing and evaluating their own STEAM tasks operationalized this philosophy, and the resultant growth in planning and implementation confirms that constructivist pedagogies foster self-direction when embedded in authentic problem contexts.

The findings of the present study also converge with Burnard et al. (2021) and Areljung (2023), who found that STEAM approaches enhance teachers' creative agency and willingness to integrate interdisciplinary strategies. However, unlike Burnard et al., who reported immediate classroom transformations, the present study suggest a more gradual and mediated process: teachers' engagement increased, but sustained pedagogical transformation requires continued institutional scaffolding. This finding also complements Stott's (2025) conclusion that the SLP acts as a catalytic intervention in advancing teacher engagement. In the current study, the SLP similarly ignites SDL but does not, on its own, guarantee long-term change. Conversely, these results diverge from Zimmerman (2016), who treated self-regulation as predominantly intrapersonal. In this study, self-monitoring achieved predictive power primarily through interpersonal communication, thereby challenging purely cognitive formulations of self-regulation. This shift from intrapersonal control to intersubjective negotiation reinforces the claim that professional learning is socially constructed.

Moreover, whereas Whitcomb et al. (2009) emphasized mentorship as the primary driver of reflective practice, the present study demonstrates that peer dialogue within short-course settings can serve a similar mediating function. This broadens the understanding of reflective scaffolding in resource-constrained contexts, where formal mentorship may be unavailable. Drawing on Freire's (1972) and Vygotsky's (1978) shared emphasis on social dialogue, the current study interprets SDL as both a moral and epistemic enterprise. Teachers participating in the SLP enacted what Freire termed *conscientização*, a deepened awareness of their agency to transform classroom practice, while simultaneously moving through a Vygotskian developmental trajectory in which guidance progressively recedes as competence grows. The empirical pattern of indirect relationships, where motivation enhances planning, which subsequently strengthens engagement, and self-monitoring fosters communication, which in turn supports engagement, can thus be regarded as a philosophical metaphor for dialogical becoming (Iwuanyanwu, 2023a): motivation and reflection find realization only through relational mediation. This interpretation also resonates with Warford's (2011) proposition that the ZPTD integrates cognitive, affective, and social dimensions of teacher development. The results of the current study empirically demonstrate this integration, the paradox of engagement (Schwartz, 2016), showing that affective motivation (the *why*) is transformed through planning (the *how*) and communication (the *with whom*) into engagement (the *what for*). The SEM model thereby provides quantitative evidence for a theory of professional learning grounded in dialogical humanism (Iwuanyanwu, 2023a).

CONCLUSION

This study modelled the dynamic relationships between four domains of teachers' SDL, motivation, planning and implementation, self-monitoring, and interpersonal communication, and engagement within a STEAM-oriented SLP for South African physical sciences teachers. The findings confirmed that the SDLI is reliable and valid in this context and that SDL domains are not merely additive or parallel predictors of engagement. Rather, they interact through mediated pathways that transform teachers' intentions and reflections into professional engagement. Specifically, motivation exerted its strongest influence on engagement when channeled through deliberate planning and implementation, while self-monitoring contributed to engagement primarily through interpersonal communication. These results advance existing SDL research by demonstrating that teacher engagement in short-duration professional learning is less dependent on isolated motivational or reflective traits than on the relational and organizational processes that connect them. The study further shows that SDL within SLPs should be understood as a situated, socially mediated capability that is activated through interaction, collaborative sense-making, and structured pedagogical design.

Implications for Policy and Practice

At the policy level, the findings suggest that national and provincial TPD frameworks should move beyond conceptualizing short courses as stand-alone upskilling events. Instead, SLPs should be recognized as catalytic spaces that initiate SDL processes requiring further institutional support. Policies could require SLPs to include explicit design features that foster planning, peer dialogue, and reflective communication, given their demonstrated mediating role in sustaining engagement. At the program design level, SLP facilitators should intentionally integrate structured planning tools, collaborative tasks, and reflective dialogue into course activities. The results indicate that creative, arts-integrated pedagogies, such as cooperative problem-solving, drama, and artefact creation, can simultaneously activate multiple SDL domains, particularly when participants are encouraged to articulate, share, and refine their thinking collectively. For facilitators and teacher educators, the findings underscore the importance of adopting a catalytic rather

than didactic role. Rather than transmitting content, facilitators should curate learning environments that support relational autonomy, enabling teachers to translate motivation into purposeful action through planning and interpersonal engagement.

Limitations of the Study

While this study provides valuable insights into teachers' SDL within SLPs, several limitations should be considered in interpreting the findings. Methodologically, exploratory and confirmatory factor analyses were conducted on the same sample. This approach was guided by strong theoretical assumptions and careful model specification; however, the possibility of model overfitting cannot be entirely excluded, and pathway coefficients were therefore interpreted with appropriate caution. The sample size, although adequate for the analyses undertaken, limited opportunities for multi-group comparisons and tests of measurement invariance. Data were generated primarily through self-report questionnaires and semi-structured interviews. These methods enabled rich access to participants' perspectives, yet they may be influenced by social desirability and recall bias. Qualitative observations strengthened triangulation, but measurement error cannot be fully ruled out. Contextually, the study focused on a single STEAM-oriented SLP for physical sciences teachers in South Africa, which supports depth of understanding but may limit transferability to other subjects or longer programs. The SEM design also permits relational rather than causal claims. Future studies with larger, diverse samples and longitudinal designs would further strengthen and extend the present findings.

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