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Motivation and STEM PhD identity development: Supervisor perspectives on the changing nature of science disciplines and science acculturation

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ABSTRACT

The nature of the PhD has shifted dramatically in recent times in accordance with the broadening of perspectives on the purposes of the qualification. This study considers the impact of this shift, highlighting the implications of changing student motivations on the PhD acculturation process, graduate identity formation, and the effectiveness of supervision practices in Science, Technology, Engineering, and Mathematics (STEM) disciplines. The study design is based on an overarching qualitative research enquiry into factors influencing supervision practice, where the perspectives and experiences of different supervisors were collated from semi-structured group interviews. We draw on Berry's Model of Acculturation to analyse the roles and interplay of motivation and culture in relation to PhD graduate identity formation, and we examine the implications thereof for effective supervision. The study reveals the multifaceted dimensions of the acculturation process within the context of PhD supervision, viz., students' motivations and identities, experiences and perceptions of supervisors, and cultural norms in the STEM community of practice. We demonstrate the shifts along these dimensions affecting PhD enculturation, showing how the alignment and discordance between student and supervisor may lead to assimilation, integration, marginalisation, and separation. This study contributes to increasing the body of research on doctoral degree completion with a specific focus on supervisor experiences in the context of the STEM fields, where PhD supervisors are facing unprecedented challenges amidst a shifting higher education landscape.

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Introduction

In the realm of academic pursuit, the PhD has long symbolised the culmination of a process of rigorous research, critical inquiry, and scholarly contribution to one's chosen field of study. The PhD has historically been positioned primarily to prepare the next generation of academic scholars, capable of contributing to the expansion of knowledge in particular academic disciplines. The traditional conceptualisation of the PhD underscored the development of expertise in specialised areas or 'academic tribes' (Becher & Trowler, 2001), often confined to specific academic domains in research institutions and universities. In recent years, however, the landscape of higher education has undergone seismic shifts in response to demands for greater responsiveness to national skills and development needs, with increasing emphasis on inter-, cross-, and trans-disciplinarity, as well as the need for greater contextual relevance of higher degrees. As Trowler (2014:19) points out, "The landscape is an exceptionally complicated one, and is quickly changing to become even more complicated as time goes on."

These shifts have prompted a fundamental re-evaluation of the nature of doctoral education as an apex qualification, with versatile skill sets and adaptable knowledge applicable across various sectors receiving greater prominence amongst the intended doctoral outcomes. Consequently, the scope and expectations of a contemporary PhD have expanded beyond academic scholarship, with greater emphasis on developing critical thinking, interdisciplinary collaboration, and transferable skills to meet the demands of an ever-evolving job market and innovation-driven economy (McAlpine, 2017; Skakni, 2018a; Hancock, 2023; Horta, Li & Chan, 2023).

The urgency to reconceptualise the PhD and re-evaluate its role and purpose within the context of the modern educational and professional landscape necessitates an understanding of the current trends and perspectives in PhD supervision (Bengtsen & McAlpine, 2022), particularly within the STEM disciplines. As such, a first level of analysis to this study presented in Cornell, Doorsamy and Padayachee (2022) leveraged the Social Realism framework (Archer, 1982, 1995, 2007; Porpora, 2013) to identify and categorise the factors (structure, culture, and agency) influencing supervision in relation to four thematic focus areas, that is, liminality and dispositions, time-to-completion, motivations for pursuing the PhD, and constraints to supervision and completion. In this paper, we draw on Berry's (1992) Acculturation framework to further probe the roles and interplay of motivation and culture as they relate to PhD graduate identity formation, and we examine the implications thereof for effective PhD supervision.

The nature and purposes of a PhD in STEM fields

The pursuit of a PhD in the STEM fields is often perceived as a pinnacle of academic achievement and research prowess - a zenith in a journey of scholarly development. Moll (2004:6) aptly characterises this endeavour as "highly systemized forms of inquiry not synonymous with the practices in everyday life that they must prepare people for, inform and challenge". In the realm of STEM, this observation not only highlights the intricate nature of research but also alludes to its dynamic role in shaping both the academic landscape and the broader context of scientific progress and innovation. At the same time, thinking of the PhD as a pinnacle invites consideration of its contrasts, such as the early stages of learning or the practical, everyday applications that research must eventually connect with. In this context, the purpose of a STEM-oriented PhD goes beyond the conventional notions of learning and extends into the realms of critical thinking, problem-solving, and cutting-edge research.

While master's level study often equips students with foundational knowledge and research skills, the PhD builds on this base by progressively encouraging intellectual independence, moving students from structured guidance to self-directed inquiry. STEM-focused PhD programmes, in common with PhD programmes across most academic disciplines, aim to foster an environment where highly specialised knowledge and skills are developed through rigorous inquiry and exploration. These programmes are designed to push the boundaries of existing knowledge, challenging established paradigms, and encouraging innovative approaches to problem-solving. At their core, they are about cultivating a cohort of independent thinkers capable of contributing to the frontiers of scientific discovery. However, Moll's (2004) assertion prompts a reflection on the detachment of such systematic inquiry from the practicalities of everyday life. This detachment underscores the need for effective translation of research findings into applicable solutions that either address real-world problems or have connections with real-world settings.

STEM PhD supervision: A changing landscape

In the STEM disciplines, the supervision of PhD candidates often revolves around guiding them in the art of conducting highly specialised and intricate research. This process is fundamentally aimed at honing students' critical thinking abilities and encouraging them to embrace a holistic understanding of the scientific method. Unlike undergraduate or master's programmes, where the emphasis might be on imparting or embedding fundamental knowledge, the PhD journey is more about delving

deeply into the unexplored territories of knowledge, often entailing the creation of new knowledge itself.

PhD candidates are also expected to be self-reliant and to function autonomously as independent researchers, a notion pointed out by Manathunga and Goozée (2007), which resonates strongly in the context of STEM fields. This autonomy is vital in fostering the self-reliance necessary for conducting high-level research. PhD candidates are expected to function as independent researchers, demonstrating the ability to identify and analyse research problems, formulate research questions and methodologies, collect data and perform analysis critically, whilst also extracting meaningful findings. The role of the supervisor, in this case, is not merely that of an instructor but of a mentor who facilitates the development of critical thinking skills and research autonomy. Successful PhD completion thus lies in the complex relationship and sets of interactions between supervisor and student. Our overarching study was conceptualised in this context and led to our critical analysis of the contemporary trends and emerging paradigms shaping the supervisory landscape employing a social realist lens (Cornell et al., 2022). In this study we revealed the intricate dynamics underlying the evolving nature of PhD supervision, uncovering nuanced themes and perspectives that define the contemporary supervisory ethos in the STEM disciplines.

One of the most prominent factors shaping the current state of PhD supervision is the exponential increase in the number of doctoral students. This surge is in consonance with governmental plans seeking to expand the pool of doctorate holders, as observed in South Africa (Herman, 2017; Herman and Sehoole, 2017), and many other developing countries (Jowi, 2021). This demand aligns with global trends in developed economies, such as the recent emphasis on increasing doctoral attainment to support economic growth and foster innovation (Santos, Horta & Heitor 2016; Sarrico, 2022; Hancock, 2023). Although data for doctoral attainment are not available for many countries, the available World Bank data does show that 36 countries had doctoral attainment of above 0.6% in 2020, which includes South Africa amongst only a handful of other non-Organisation for Economic Co-operation and Development (OECD) countries (Sarrico, 2022). In addition to growing doctoral attainment, the South African context bears similarity to OECD countries, in that the largest proportion of new entrants to doctoral programmes is in the STEM fields (Mouton et al., 2022; OECD, 2022). Consequently, STEM supervisors are faced with the challenging task of accommodating more students while maintaining the quality of supervision, presenting a strain on the traditional model of one-on-one mentorship.

The demographics of graduate students are also undergoing a marked shift, contributing to the changing landscape of PhD supervision. Diverse student backgrounds, perspectives, and skill sets necessitate a more inclusive and adaptable supervisory approach. Additionally, the academic pipeline is no longer the sole trajectory for PhD graduates. The widening scope of doctoral education, as noted by Sarrico (2022), now requires the preparation of candidates for careers beyond academia, prompting supervisors to tailor their guidance to suit a broader range of professional pathways. Moreover, the motivations of contemporary students are evolving in tandem with the changing nature of work (McAlpine, 2017; Skakni, 2018a; Skakni, 2018b; van Rooij, Fokkens-Bruinsma & Jansen, 2021; Diogo, Gonçalves, Cardoso & Carvalho, 2022; Horta et al., 2023), alongside an increasing need to comprehend how shifts in the labour market are influencing the expectations placed on doctoral graduates. Mouton et al. (2022) illustrate this point in a study of PhD graduates in South Africa. However, these shifts are not confined to the South African context, as studies conducted in the United Kingdom (UK), Australia, and the United States (US) have observed similar trends, as reported in the OECD (2023:14) policy paper on "Promoting Diverse Career Pathways for Doctoral and Postdoctoral Researchers".

The traditional academic employment landscape is also facing challenges. The scarcity of academic positions, as highlighted by OECD reports (OECD, 2021; OECD 2023), is leading to more PhD graduates seeking careers outside academia (Walters, Zarifa & Etmanski, 2021). This trend necessitates a re-evaluation of the skill sets and competencies cultivated during the doctoral journey, underscoring the importance of incorporating elements of professional development and career guidance into the supervision process. This calls for a more nuanced approach to supervision, focusing not only on disciplinary knowledge but also on the application of this knowledge across diverse contexts, as the current workforce demands versatile and adaptable skill sets. In a similar vein, our previous study (Cornell et al., 2022) highlights the associated issue of motivation and the profound role this plays in the formation of doctoral identity. The study emphasises the pivotal role of motivation in shaping the trajectory of doctoral research and the subsequent development of a coherent scholarly identity. Motivation, as an intrinsic driver of academic pursuit, influences the selection of research topics, the level of engagement, and the overall commitment to scholarly inquiry. As our earlier research illustrates, there is significant interplay between motivational factors and the evolving dynamics of PhD supervision, with implications for the multifaceted process of academic acculturation and graduate identity formation within STEM disciplines.

Motivation for the study

Within the context of a changing higher education landscape, the relationship between supervisors and their students has also become increasingly complex and intricate, posing significant implications for the holistic development of doctoral candidates. The supervision process has, therefore, also experienced concomitant shifts and adaptations to accommodate these various influences. Supervisors now must provide doctoral education that not only develops disciplinary expertise in a context of blurring disciplinarity boundaries and increasingly diverse students but also cultivates a broad set of skills that are essential to successfully navigate an evolving global professional landscape. By recognising and responding to these influential factors, contemporary PhD supervision can better equip candidates to deal with the modern complexities they may face in the professional world.

The need for greater responsiveness in PhD supervision is also indicated by the surge in research into PhD education, especially on the roles and interplay between supervisors and students. We note, however, that most studies have focused predominantly on students' perspectives of this complex relationship, with little emphasis on supervisors' experiences and views. This study aims to address this gap in the literature by focusing on the supervisors' perspectives.

The study is also motivated by the researchers' own interest as postgraduate supervisors located within STEM fields at different institutions. Our shared experiences of the factors and challenges that influence our supervision roles has led us to question both the nature and purpose of the PhD, and how supervision practices have been influenced and consequently re-shaped in recent years.

Study aims

The overarching objective of this research is to examine the current factors conditioning supervision practices within PhD programmes, with a specific focus on the experiences of PhD supervisors in STEM fields. By delving into these factors, we seek to identify potential constraints or enablers that may impede or encourage necessary shifts in response to the evolving expectations and outcomes of PhD education. The primary aim of the research is to determine the essential changes required to enhance the preparation of STEM PhD graduates, ensuring their success in diverse career paths. The investigation endeavours to equip both current and future supervisors with the necessary knowledge and tools to effectively respond to changing circumstances and expectations within the

academic landscape. More specifically, the study reported on in this paper aims to examine the roles and interplay of motivation and culture, which we identified as significant areas of influence on PhD graduate identity (Cornell et al., 2022). Our aim is to shed light on how varying student motivations and different acculturation approaches adopted by students might pose unique tensions and challenges for STEM PhD supervisors in disciplines often characterised by entrenched norms and values. This research seeks to contribute insights that can inform supervision practice towards fostering a more supportive and enriching academic environment in contemporary PhD programmes.

Theoretical and analytical frameworks

Social Realism as an underpinning framework

Identifying and disentangling the factors influencing PhD student success is complex and requires appropriate theoretical and analytical frameworks. Underpinning the first level of analysis in this study is the Social Realism framework (Archer, 1982, 1995, 2007; Porpora, 2013), which was used both as a theoretical and analytical framework in our preceding paper (Cornell et al., 2022), which led to the present study.

Postgraduate supervision is an inherently social act occurring within the social system of higher education on one level, and within the culture of science (Tindimubona, 1991 (as discussed at the end of this subsection); Yuan, 2022). Social Realism theory, therefore, provided an appropriate framework for the preceding study, which afforded the identification and categorisation of the structures, cultural influences, and agential factors that influence social systems. Archer (1995) theorises that the influences of these components (i.e., Structure, Culture, and Agency) on each other, and on the system, must be separately and sequentially analysed to form an in-depth understanding of the influence of each of the components. It then becomes possible to subsequently examine the interplay between these influences, and possible mechanisms that may be leveraged to effect changes.

The study methodology presented in Cornell et al. (2022), consisted of an in-depth enquiry of the perspectives and experiences of supervisors from different STEM disciplines using a semi-structured focus group interview format. The study was granted ethical clearance by the two participating institutions, from which a broad pool of supervisors with varying levels of experience from different

disciplinary backgrounds were purposively sampled and invited to participate. The participating institutions are large comprehensive public universities that are research intensive and internationally oriented. The semi-structured interviews were conducted using three separate focus groups, each comprising four supervisors from different disciplinary backgrounds (mathematics, physics, engineering, biology, and computer science) and levels of experience. It should be highlighted that, despite their differences in supervision experience and backgrounds, participants expressed views that were mostly in agreement and we found data saturation occurring after the second group of interviews - i.e., there was no change in the relative prevalence of views expressed, indicating 'theoretical saturation' within the boundaries of our thematic analysis (Guest, Bunce & Johnson, 2006). Participants were asked about their experiences and perspectives with respect to four thematic focus areas, that is, liminality and dispositions, time-to-completion, motivations for pursuing the PhD, and constraints to supervision and completion, identified from our initial enquiry into the overarching research question (Cornell et al., 2022). The responses were systematically coded into these thematic areas, followed by further analysis and categorisation into the social realist components (i.e., Structure, Culture, and Agency). This level of analysis revealed the intersections, and their relative strengths, between the four thematic areas and each component of the social realism framework. An especially prominent set of interactions noted in this first part of the study was the roles and interplay of motivation and culture, a finding that warranted further consideration into how these factors, in particular, collectively, influence PhD graduate identity formation, leading to the present analysis.

Motivation and science culture

To appreciate the interaction between motivation and culture more fully, the identity supervisors have sought to foster in their students stems from the cultural identity of science. Science culture, as a concept, embodies the intricate interplay between scientific knowledge, societal values, and cultural beliefs, shaping the dynamics of scientific practices and the dissemination of knowledge within a given society. According to Yuan (2022), science culture transcends the mere dissemination of scientific information, encompassing the broader social, ethical, and philosophical dimensions that influence the production, communication, and reception of scientific knowledge. Yuan highlights the multifaceted nature of science culture, emphasising its role in fostering a symbiotic relationship between scientific advancements and societal aspirations. This view of science culture aligns with the view of academic disciplines as flexible, adaptable, evolving systems shaped and influenced by various social and material factors, proposed by Trowler, Saunders & Bamber (2012).

By elucidating the social, cultural, and material underpinnings that shape the scientific enterprise, Yuan (2022) underscores the significance of understanding the intricate intersections between science and culture in navigating the complex global challenges of the contemporary world.

Tindimubona (1991) also emphasises the influence of social factors on science, proposing a more diverse view of science culture as an amalgamation of traditional African values and Western scientific paradigms within the African scientific landscape. Tindimubona's analysis emphasises the transformative impact of science culture on Africa's socio-economic development, shedding light on the challenges and opportunities inherent to the assimilation of scientific knowledge within the diverse cultural fabric of the continent. The notion of science culture may thus be broadened when there is greater integration between social and material contexts, and students' identities, in relation to the scientific epistemology. In this respect, greater consideration of students' identities (which directly links to their sense of motivation and agency), and how this interacts with science enculturation and the process of *becoming* science PhD graduates, becomes crucial.

Berry's Acculturation Strategies and PhD identity formation

As identity can take on several different meanings when used as an analytical lens, there is a need to further clarify this term and what context it is intended to bring meaning to in this study, before delving into identity formation in relation to acculturation.

Gee defines identity as the "kind of person one is recognized as being, at a given time and place", describing it as being dynamic in nature and subject to one's interactions in a given context (Gee, 2000:99). Brown builds on Gee's definition by explaining how identity also draws its meaning from the process of interpretation whereby "individuals signal meaning that seeks to assist others in identifying them as a particular kind of person" (Brown, 2004:812; Brown, Reveles & Kelly, 2005:783). In the context of this study, identity is a student's sense of who they are and who they want to become on the one hand, and, on the other, what their supervisors and peers perceive as a legitimate PhD identity. The student's identity is reflective of their own cultural and academic background, worldview, and personal motivations, but this identity is also given meaning by their own signalling, how that is perceived by others, and the interpretation of PhD identity that is rooted in science culture and the STEM community cultures. In this respect, Ryan and Deci's (2000) self-determination theory (SDT) provides useful characteristics associated with different types of motivations for pursuing a PhD.

Our reasons for drawing on an identity lens in our analyses resonate with those of Carlone and Johnson (2007), in their model of science identity. More specifically, we are seeking to better understand how PhD students' emerging identities in STEM relate to "their more enduring sense of who they are and who they want to become" (Carlone & Johnson, 2007:1189). As demonstrated by Carlone and Johnson (2007), it is necessary to understand how students assimilate or dissimilate, and negotiate, cultural norms in the STEM community of practice into which supervisors aspire to enculturate them during their PhD candidature (Lave & Wenger, 1991; Wenger, 1998).

Identity formation is generally facilitated through a tacit process of acculturation in which students gradually assimilate disciplinary ways of thought and practice (Barradell, Barrie & Peseta, 2018). Guided by our initial findings, we sought to frame this acculturation process in the context of an evident clash between emerging students' identities, in which their motivations are firmly embedded, and the PhD identity within the STEM community of practice into which supervisors aspire to enculturate students. We therefore draw on Berry's acculturation strategies (integration, assimilation, separation, and marginalisation) to illustrate alignment or discordance in supervisor and student motivations, and how this could influence success and challenges in the context of PhD supervision (Berry, 1992). We note, however, that while useful for analytical purposes, Berry's framework does not necessarily capture the complexities of acculturation and may pose the potential challenge of oversimplification of a highly complex phenomenon (Kunst, Lefringhausen, Sam, Berry & Dovidio, 2021). We remain especially alert to issues such as ideological and epistemic bias, and the intersections between personal choice and individual agency, and systemic biases and discrimination (Rudmin, Wang & de Castro, 2017), which may be explored more deeply in further research into postgraduate experiences.

Using Berry's (2006) Acculturation model, we draw analogies of alignment and discordance in the context of STEM PhD supervision, specifically with respect to motivation and identity. Although the adapted model in Figure 1 is presented visually as four quadrants for interpretive clarity, we conceptualise these categories as part of a continuum. This is because the boundaries between alignment and discordance in practice are not always clearly defined, and individuals may occupy positions that span across categories. However, the extremes such as strong alignment or pronounced discordance are typically more distinct and recognisable and serve as useful reference points for interpretation. The continuum framing allows us to examine the interplay between culture and agency in a more fluid and dynamic way, where shifts in motivation and identity may occur over

time. This perspective may be useful to supervisors in identifying, understanding, and responding to alignment or discordance at an early stage so that they may support students more effectively.

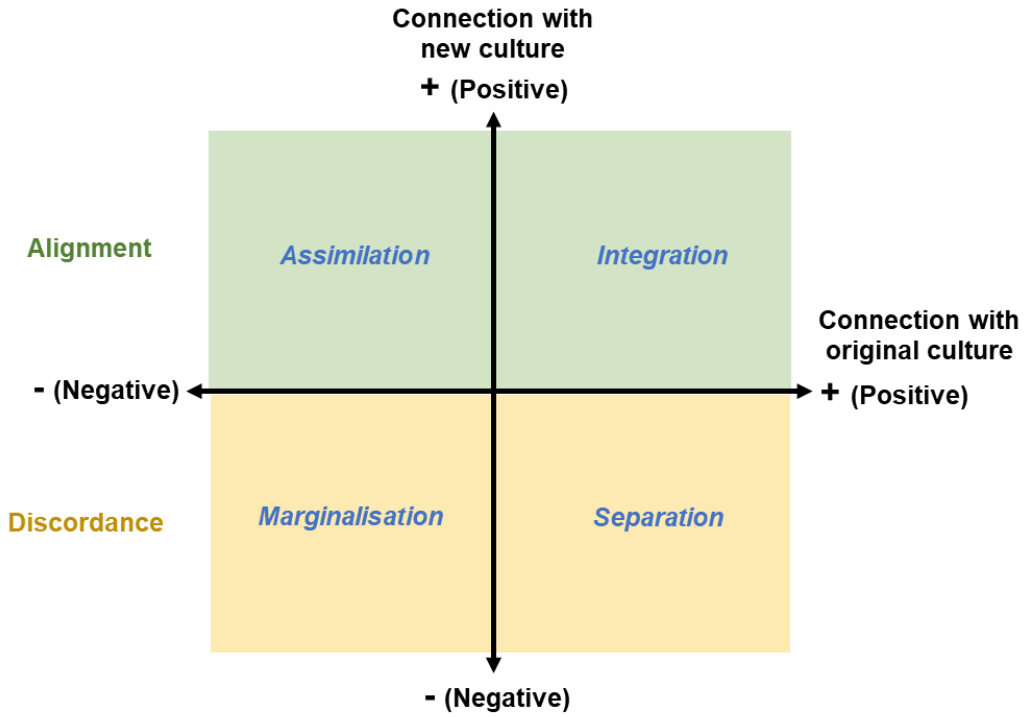

Figure 1: Illustration of alignment or discordance in the context of STEM PhD supervision as a continuum of acculturation categories, adapted from Berry's model (Berry, 2006).

Assimilation: This is when the student completely adopts the norms and values of traditional STEM PhD candidature, fully committing to the new culture of research. An example of this would be a full-time student who identifies as a researcher and wants to become an academic, scientist, and/or researcher. This is typically the case where the student is intrinsically motivated and would follow an apprenticeship model of supervision which tends to be preferred by many supervisors as it is how most traditional PhD programmes are structured.

Integration: This refers to instances where the student participates in the new research culture, adopting some of the norms and values expected of them, yet still maintaining a strong commitment to their own motivation and identity. An example of this would be a part-time student who is highly motivated (potentially extrinsically) and wishes to obtain a PhD, but who does not necessarily see themself as an academic, scientist, and/or researcher.

Separation: This category refers to the student who rejects, and does not practise or adopt, the STEM PhD cultural norms and values. In this case, the student may be extrinsically motivated and is

likely to lack commitment to their PhD study - i.e., their motivation is more externally regulated, and they have no or less interest towards achievement (Ryan & Deci, 2000).

Marginalisation: This refers to the student who does not adopt the PhD culture and norms but is also not necessarily clear on or committed to their own motivation and identity, for example, the student who is uncertain about career prospects and lacks motivation. This would be categorised as 'amotivation', within Ryan and Deci's self-determination continuum, which is when students "do not act at all or act without intent - they just go through the motions" (Ryan and Deci, 2000:72). In lacking motivation and not seeking to join the PhD culture, these candidates seemingly leave their studies rapidly.

Reflections on acculturation in the context of PhD supervision

The process of acculturation within the context of PhD supervision embodies multifaceted dimensions, such as the motivations and identities of students, experiences and perceptions of supervisors, and the cultural norms in the STEM community of practice. For students following the traditional academic pipeline and motivated by potential academic careers, there is usually greater alignment between student and supervisor, and consequently greater chance of assimilation. In traditionally hard disciplines, such as physics and mathematics, this alignment seemingly flows from the student's intrinsic motivation, which can be associated with developing self- and peer-recognition as academic discourse insiders (Kutz, 2004). The "opportunities for self-direction", which are typically associated with the traditional PhD programmes, may also contribute towards easier assimilation with the traditional academic pipeline (Ryan & Deci, 2000:70). Similarly, there may be alignment between supervisors and highly motivated part-time students who are employed outside of academia, where the result of STEM PhD acculturation is towards integration rather than assimilation. Our findings in this regard agree with the outcomes and implications reported by Litalien, Toth-Kiraly, Guay and Morin. (2024:3), where higher levels of "autonomous forms of motivation", irrespective of intrinsic or extrinsic motivation (where regulation style is either identified or integrated (Ryan and Deci, 2000:72)), were found to be a "critical driver of students' persistence and research productivity".

In contrast, challenges surface when disparities emerge between students' motivations and their perceptions of the PhD journey compared with those of their supervisors, potentially leading to marginalisation or separation within the academic sphere. Part-time students, for example,

completing PhDs for career advancement in fields aligned with their research may not necessarily be motivated by a potential academic career or identify themselves as scientists/researchers. Although there may be discordance between where they see themselves and the traditional mould of a STEM PhD researcher, their motivations for attainment can be an enabler for integration.

When the discordance between students' motivations and perceptions of the purpose of the PhD increases, as compared with those of the supervisor, the likelihood of marginalisation or separation also increases. This typically occurs when students are either lacking motivation or are extrinsically motivated, but not sufficiently for them to connect to the new culture. Supervisor 4 commented on their experience with this: "For some part-timers, as long as the workplace is fine, they move according to the push from the university's side".

Note that these motivations are also indirectly signalled in interactions with supervisors as they seek to evaluate the development of PhD attributes and emerging PhD dispositions. For example, a key PhD disposition valued by supervisors, as found in our interviews, is that of independence, which was summed up nicely by Supervisor 1: "...when we look for the key dispositions, I would say it's independence ... and this is when I have the 'aha moment' that the student is now thinking like a PhD" (Cornell et al., 2022:154).

Examining the motivations of experienced supervisors participating in our study also shed light on the intrinsic drivers that have historically guided the trajectory of the traditional PhD pursuit. Most experienced supervisors participating in our study reported being influenced and motivated mostly by their own intellectual curiosity and personal background.

Supervisor 8, for example, expressed intrinsic motivation answering, "I wanted to be a researcher … the quest for finding out things…", when asked about their motivation for pursuing a PhD.

Supervisor 5 commented that their reason for pursuing a PhD related to a personal background from which they drew motivation: "...from a family of studious people. PhD was the expected path".

A similar reason was shared by another participant, Supervisor 1: "My (masters) supervisor suggested that I do a PhD…". Unsurprisingly, these motivations align more with the culture of science and the traditional PhD identity affording greater chance of assimilation and is the likely reason for them entering academia and becoming researchers and research supervisors.

When asked to contrast their own motivations to those of their PhD students, most supervisors agreed that in their experience there was a growing number of students with motivations and aspirational identities different to their own, suggesting a shift in motivations. In contrast, most participants felt that current students seek the PhD qualification to enhance their career prospects and competitiveness in industry.

This sentiment was summed up by Supervisor 6: "They want the end result, they don't necessarily want to be scientists. They want the qualification that will give them a good job" (Cornell et al., 2022:154), and was echoed by Supervisor 1: "The (PhD) title is very coveted."

This signifies a departure from the conventional aspirations of becoming researchers, which we argue could become a potential source of discordance between supervisors and students. This shift, and the accompanying potential for discordance, is further reinforced by the increasing enrolment of international students in South African PhD programmes, influenced by aspirations of global exposure and enhanced career prospects (Mouton et al., 2022). The share of international doctorate graduates in South Africa is similar to that of the UK – i.e., approximately 45% of the total doctoral graduates in 2017 (OECD, 2019). In South Africa, most of these international doctoral students are from other parts of the continent (Mouton et al., 2022), while the majority of international doctoral students in the UK are from non-European Union countries (Westphal & Ilieva, 2022). International PhD students may also be faced with other challenges and constraints (finances, housing, visas, having to support families, language barriers). These non-academic challenges can have a significant influence on a student's ability to assimilate or integrate during the PhD process, and our findings suggest that supervisors are often unsure of how to support students in these areas. Importantly, these constraints may not be limited to international students, however, and it should be noted that there tends to be "More pressure on local students who are mainly part-time because of the need to support families", as indicated by Supervisor 2. This resonates with the fact that, in South Africa, most local doctoral students study part-time while employed. This translates to an older average age profile for students in South Africa when compared to countries in Europe and the US, where most doctoral students study full-time (Mouton et al., 2022).

Supervisors also indicated that they have found many students are motivated by the desire to emigrate or gain international exposure. Supervisor 4 suggested access to the South African job market as a key motivation for their international students, with the following comment: "Students seeking to advance their schooling, as a way of continuing their access…". Supervisor 3 echoed the

sentiment of Supervisor 4 regarding the PhD serving as a vehicle for international exposure and potential emigration, adding that in their experience: "Some students see postgrad studies as international exposure, from a skills perspective…".

The influence of motivation on the duration of PhD completion and the extent of STEM PhD enculturation cannot be underestimated, as intrinsic motivation is often entwined with various external factors such as career advancement for part-time students and visa limitations for international students, etc. Moreover, time constraints, often exacerbated by what some supervisors referred to as the "sausage factory approach" (that is, the increasing massification of PhD programmes), poses a significant challenge (Cornell et al., 2022:156). These constraints impede the depth and quality of interactions between supervisors and students, where this limitation further hinders the effective transition of students across different acculturation categories.

The elements conditioning supervision practices are thus shaped by a complex interplay of various intrinsic and extrinsic factors that significantly shape and influence both the disciplines themselves, and the dynamics of the supervisory relationship within these evolving disciplines. As supervisors engage with increasingly diverse cohorts of students within higher education and disciplinary contexts that are also in a state of flux, tensions are inevitable. It can be argued that this is particularly evident in the context of STEM disciplines, stemming from discrepancies in student and supervisor motivations, cultural differences, and different expectations. A crucial element in navigating these challenges lies in acknowledgement by supervisors that not all PhD students will (or want to) assimilate into the STEM PhD culture and attempts to understand the nuanced intricacies of students' motivations and contextual identities should be an integral part of the early stages of the supervisory journey. Recognising the diverse motivations and backgrounds of students is pivotal in shaping both the PhD research project and the set of supervision practices needed to cater to individual students' needs and aspirations. By fostering a comprehensive understanding of students' motivations and contextual identities from the outset, supervisors can establish a supportive framework that encourages open communication and mutual respect. Chen, King, Li and Xu (2024) provide empirical support, based on SDT, for the proposition that the students' research environments affect their motivation, which then has implications for their well-being. Our findings here similarly support this proposition and extend the implication that this early understanding of motivation forms the cornerstone for cultivating a nurturing and inclusive environment conducive to the holistic development of students within the academic sphere. It is also interesting to note the strong resonance between the implications from our study and those of other recent studies that

consider the role and interplay of PhD students' motivations (Chen et al., 2024; Litalien et al., 2024), despite the differences in study locations and perspectives (that is, supervisors' views and students' views).

Moreover, linking students' motivation and their potential acculturation experiences to the development of their science identities (encompassing notions of performance, competence, and recognition), would enable supervisors to further tailor their guidance and mentorship to suit the unique needs and expectations of individual students. Integration of these elements would foster a cohesive identity that aligns with the values and practices of the academic community, while also promoting greater epistemological and ontological access by allowing for greater integration of their own professional experiences and expertise in an amalgamation of social and disciplinary practices. Supervision practices that embrace students' individual identities and experiences may thus lead to an iterative cycle of restructuring of disciplines, based on how disciplinary knowledge is represented and applied in different contexts. This social practice theory view of disciplines (advanced by Trowler et al.,, 2012), challenges the notion of 'PhD dispositions' mentioned by some study participants. However, such approaches also represent an opportunity to reconsider the notion of dispositions for disciplinary practitioners who, "in conjunction with external forces, may reshape disciplinary knowledge in different practice clusters into localised repertoires" (Trowler et al., 2014:3).

Within the supervisory relationship, tensions and discordance may also arise from the misalignment of expectations, differing communication styles, and cultural disparities between supervisors and their students, potentially leading to separation or marginalisation. Addressing these tensions requires a proactive supervision approach that fosters open dialogue, mutual understanding, and the establishment of clear communication channels. The key to shifting students towards greater identification with the culture of science, through assimilation or integration, lies in fostering a holistic understanding of students' motivations, cultural backgrounds, and existing professional identities, while also recognising the nuanced interplay between science identity and individual perceptions of performance, competence, and recognition. By integrating these elements into the fabric of supervision practices, supervisors can cultivate an inclusive environment that supports students to negotiate the complexities of the academic journey with confidence and resilience, while also affording them the opportunity to contribute to, and advance the knowledge and practices of the discipline (Riva, Gracia & Limb, 2022). This approach proactively fosters a sense of belonging and professional fulfilment while contributing to the evolution of the disciplines, which is dependent on the richness of varied experiences and perspectives (Siltanen, Chen, Doyle & Shotwell, 2019).

Conclusion

Many factors influence the PhD journey; thus addressing these complexities necessitates a nuanced understanding of the various factors conditioning supervision practices and tensions. Early recognition and comprehension of students' motivations and emerging identities, coupled with an acknowledgment of the multifaceted nature of science identity encompassing performance, competence, and recognition, are imperative for fostering a supportive and inclusive academic environment. Such an approach, as highlighted by our study, is instrumental in facilitating a more holistic and adaptive form of acculturation towards enhancing students' overall academic experience.

In conclusion, it is crucial to recognise that the process of PhD acculturation requires consideration of a wide array of factors, with completion or attrition often shaped by complex interplays and entanglements between supervisor perceptions of PhD outcomes, including PhD attributes and dispositions to be developed, students' individual motivations, institutional constraints, and the evolving landscape of doctoral education. Traditional notions of PhD acculturation thus require reconceptualisation and a broadening of the markers of PhD achievement to accommodate the diverse aspirations and identities of contemporary PhD candidates. This would foster an inclusive environment that embraces and celebrates the richness of diversity within the academic sphere. Such an approach is essential for enhancing students' sense of belonging and fostering a culture of inclusivity and innovation within the realm of doctoral education.

Furthermore, as the motivations of supervisors and students diverge, particularly with more students aiming for industry rather than academia due to dwindling numbers of positions, it is crucial for supervisors to adapt their approaches to produce PhD graduates who are equipped for diverse career paths. Institutions must recognise this shift and provide support and resources for supervisors to mentor students effectively for both academic and industry careers. This may involve incorporating career development modules into doctoral programmes, facilitating networking and work-integrated learning opportunities within industry and with industry professionals, and fostering a culture that values authentic, interdisciplinary skills and experiences.

Moreover, institutions should consider implementing tailored support mechanisms that align with students' motivations, especially when these motivations fall within the integration or separation categories of Berry's Acculturation model. This might involve personalised mentorship programmes,

career counselling services, and flexible funding opportunities. By acknowledging and accommodating the varied aspirations of doctoral students, institutions can create a more inclusive and supportive environment.

As such, these results seem to indicate a proactive approach to support both students and supervisors in navigating the evolving demands of academia and industry. That is, we argue that a broadening of the notion of *academic culture* and *academic achievement* is needed, to enhance students' sense of belonging and success. However, we note that this work was drawn from interviews with STEM-based supervisors and as such is limited to only STEM-based PhD studies. The motivations and conclusions we have drawn may apply more broadly by expanding this work to other fields which would be able to establish this as a general feature for all PhDs.

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