Volume 38 (1), pp. 29–51
http://orion.journals.ac.za

ORiON
ISSN 0259–191X (print)
ISSN 2224–0004 (online)

Development of an early career academic supervisor in Statistics - A discussion towards a guiding rubric

I Fabris-Rotelli* MJ von Maltitz† A Smit* S Das* D Roberts‡
G Maribe* D Maposa§ FM Corrêa¶

Received: 10 May 2022; Revised: 26 June 2022; Accepted: 26 June 2022

Abstract

This discussion paper delves into the current state of academic Statistics in South Africa, specifically the development of an early career academic supervisor in Statistics. The discussions held by the authors on this topic since 2020 have resulted in clear need for action by early career academics in Statistics. This discussion paper motivates a solution involving a guiding rubric for the doctoral thesis coupled with an active early career supervisor network across South Africa.

Key words: Capacity, doctoral supervision, early career academic, mentorship, Statistics

1 Introduction

This paper is a compilation of the challenges identified for first-time research supervision; challenges that have come to light during discussions that the authors have had as a group of early-career academics. The pressures of responding to the academic roles within a Statistics department — a field already known to be in 'crisis' — led to these discussions. The purpose of this research group was to holistically document the discussed challenges, both tangible and intangible, that are experienced by both the research supervisor and the student. This paper thus aims to initiate a concrete review on supervisory capacity within

*University of Pretoria, South Africa, email: inger.fabris-rotelli@up.ac.za
†University of the Free State, South Africa
‡University of Kwa-Zulu Natal, South Africa
§University of Limpopo, South Africa
¶Rhodes University, South Africa

http://dx.doi.org/10.5784/38-1-716

academic Statistics, and identify possible solutions to alleviate the identified challenges in a logical manner.

The crises identified in academic Statistics are not entirely new. In 2004 a workshop was held in the US on the future of Statistics and a report was compiled; see [36]. In 2007 a similar workshop was held in the UK; see [56]. Closer to home, Botha and Prinsloo [10], from the University of South Africa, conducted an exploration of the state of academic Statistics in 2008, in which the overarching issues included the declining number of academic statisticians alongside the continued increase of undergraduate students enrolling in Statistics modules. Fewer academic staff results in reduced postgraduate supervisory capacity, thus producing fewer postgraduates, and subsequently not replenishing the loss in academic staff; a complicated cycle to escape from.

Statistics departments find themselves positioned within different faculties across various South African universities, for example within commerce, natural science, or engineering, and sometimes even with stand-alone entities outside these faculties, such as in Biostatistics within health sciences or Psychometrics within social sciences. Further, a Statistics department themselves may often not be structured as a stand-alone department, rather being merged at many institutions with departments such as Operations Research, Data Science, Mathematics, or Actuarial Science. In many cases, the Statistics discipline is merged into the modules offered at other departments. Thus, the importance of statistical training in other disciplines is often acknowledged outside of Statistics departments, resulting in the Statistics departments having to provide "service" courses for other degrees. The home for Statistics is thus based on the focus of an academic institution. While this does not seem like a serious issue, it comes into play when one looks at degree requirements and examination processes at the postgraduate level. The overarching process of the home faculty will guide this, leading to differences in the same discipline between academic institutions. These differences may not be transparent either, resulting in disparate assumptions by external entities. It is vital that the core discipline of Statistics must be nurtured within the Statistics departments to maintain the quality of the Statistical education that is offered on so many levels to so many separate entities. With this in mind, the consistency in assessment of doctoral research across institutions needs attention. Limited focus on core Statistics research when instructing examiners provides little guidance for early-career supervisors.

This paper sets out to show that academic Statistics in South Africa still remains in crisis, and requires urgent planning and collaboration across various stakeholders within South Africa to provide actionable and sustainable solutions.

2 Background

The discipline of Statistics falls within the broader Mathematical Sciences field. Others in the field are Mathematics, both pure and applied, Operations Research, and Theoretical Computer Science; see [1]. A 2013 report, [1], compiled by the American National Research Council, discusses the status of Mathematical Sciences and its predicted path towards the year 2025. It argues that the disciplines in Mathematical Sciences should be considered as a whole, and their interactions strengthened. It is acknowledged therein that Mathematical

Sciences has, over the last 10 to 20 years, become intertwined with other disciplines.

The role of the Mathematical Sciences academic community is to advance the Mathematical Science disciplines, that is, to develop core theory. This is done while applying the theoretical advancements to other disciplines, usually through collaborations. There is danger in these collaborations in not advancing one's own field in Mathematical Sciences by only applying existing approaches in other disciplines. While this is vitally important for research in the bigger context and valuable within those collaborative disciplines, it is suggested that a doctoral candidate in Mathematical Sciences produce advancement in the Mathematical Science fields.

Further, within South Africa there is increasing pressure on Mathematical Sciences graduates to enter the workplace rather than pursue further postgraduate studies, with the Statistics industry being particularly boosted by the growth of 'Data Science' and the 4^{th} Industrial Revolution. Two primary factors can be isolated as those preventing the correction of this. *First*, academic salaries in Mathematical Sciences are not comparable to what industry would pay at the same level of qualification. Young academics may hold out in a junior academic position for a while, but are often dissuaded by the relatively low pay for the relatively high current academic pressures in South Africa, *i.e.* large undergraduate teaching loads, administrative responsibilities, and requirements to produce non-negligible quantities of research outputs. *Second*, the National Research Foundation (NRF) postgraduate student funding, and other public funding, is not attractive to a student when industry opportunities are offering more, particularly when considering university course registration fees and the basic living expenses of a full-time student. Ultimately, this two-directional pull of the young academics away from academic and into industry results in an ageing academic group within South Africa.

In response to the crisis in Statistics, the NRF acknowledged the industry pull, and from 2015 provided funding to support postgraduate students who would enter academia during and after their PhD. The grant provides larger bursaries than the standard NRF bursaries, as well as funding to bring in expertise to train young staff. This is a breakthrough for the discipline of Statistics in South Africa, and the fruits should be visible in the coming years. This seed funding is in its final stages with the last new postgraduate cohort starting in 2022.

Despite the aforementioned initiative, the lack of doctoral-level research supervision skill and capacity is evident across South African Statistics departments. This is due to a long history of limited academic Statistics staff and the retirement of many senior researchers in Statistics over the last 15 years.

An early-career research supervisor in Statistics thus has limited mentorship available in South Africa. As academics, turning to literature for answers seems natural. However, there is limited literature on doctoral supervision in Mathematical Sciences. Vekkaila *et al*, [61], considers supervision in this field and finds that the main reason for candidates quitting is the lack of meaningful and functional relationships with supervisors. Barnes *et al*, [5], conducted a cross-disciplinary study on doctoral supervision to investigate differences across disciplines. They found similarity issues across disciplines, but suggested that more research is needed before any specific conclusions can be drawn. The study was broad, focusing on the fields of Education, Humanities and Fine Arts, Natural Sciences

and Mathematics, and Social and Behavioural Sciences. Future research could look at the supervision at smaller subdivisions such as is done in [7] when characterising fields by three types. In [38], Maor and Fraser look at postgraduate supervision within Natural Sciences but with no focus on Mathematical Sciences. An interesting compilation by Dietz *et al* [19] provides a handbook for supervision crossing South African and Dutch borders. However, once again, there is no mention of discipline differentiation nor Mathematical Sciences. Grevholm *et al* [24], published in *Educational Studies in Mathematics*, is the only paper in the journal discussing supervision. Within this journal, Duffin and Simpson [20] discuss cognitive empathy and the candidate's threshold transition; Smith and Hungwe [55] discuss three-way of viewing mathematics — a formal system, a set of procedures to use, and the understanding of mental objects; Herzig [28] unpacks factors influencing one's decision to do a PhD in Mathematics; Carlson [12] measures graduate success in solving problems; and Grevholm *et al* [24] suggest research groups for more efficiency. The latter, however, requires experienced supervisors and well-established research teams. Within the South African Statistics context, this still needs to develop; young supervisors need the skills and confidence to enable them to work independently and successfully. Without significant mentorship, this usually has to be done on an individual basis. There thus seems to be limited investigation into understanding supervision in Statistics.

Having recently obtained their PhD, young academics find themselves in a conundrum with regard to the immediate requirement to supervise postgraduate students (a key performance indicator for their permanent posistion) without a mentor and without having yet had the opportunity to understand the supervision process from the supervisor's angle. This situation is pervasive, and is not conditional on the status of a university or the discipline in South Africa. The push to do research, teaching (which is heavy at the undergraduate level), supervision (with limited mentorship and a lack of training opportunities), and still possibly even some administrative tasks, takes an undue toll on young academics. On the contrary, the academic experience should be a positive one —– for both the student and the young academic —– if we hope to foster continued growth in academic Statistics.

As already pointed out, this large workload stems from the limited number of academic staff in Statistics and the resulting need for more doctoral graduates in Statistics. Both staff and graduates are drawn to industry, which further compounds the crisis. Research into requirements from both academic and non-academic organisations indicates a need for graduates, and specifically doctoral graduates, with qualifications in scarce skills fields (see, e.g., [25]), namely science, engineering and technology (SET) or science, technology, engineering and mathematics (STEM). This sentiment echoes findings from the World Bank when reflecting on building a knowledge-based society for Africa; see [8]. The South African National Development Plan (NDP) also recognises that innovation and growth in science and technology are of paramount importance to the country in its bid to compete internationally; see [16, 46]. To address the required growth in doctoral graduates in SET programmes to feed into the knowledge economy, the number of doctoral supervisors should also grow to ensure sustainability.

In the document "Are we producing enough Doctoral graduates in our Universities?", [45], the Department of Higher Education investigated the progress South African universities

have made in addressing the NDP objective of increased doctoral students. Key findings from this document show a year-on-year upward trend in the overall number of doctoral graduates. However, this trend is lower than in comparable countries with numbers seemingly reaching a plateau since 2019. This trend is also observed amongst academic staff with doctoral degrees to act as future supervisors. The average number of permanent staff with a doctorate as the highest qualification in South African universities remains less than 46%.[1] If the trends set between 2010 and 2017 do not dramatically increase, the doctoral targets of the NDP will not be met. Although the overall number of doctoral enrolments and graduates increases annually at South African universities, and remains consistently high compared to other study fields, the number of masters and doctoral graduates does not follow the same trend. The proportion of SET doctoral graduates consists of approximately 52% of all awarded degrees. Between 1996 and 2012 the number of SET doctoral graduates increased from 43% to 53%, but this has since remained relatively unchanged; see [15, 45]. The causes of this current lack of growth in student numbers and graduates in SET doctoral programmes in South Africa are not clearly defined. The simultaneous problems of lack of substantial growth in student numbers, young academics exiting to join industry, and the continued discourse between theoretical and applied statistics and data sciences all contribute to the lack of sustainability of career-academia in Statistics; see [27].

The growth and maturing of an academic in any discipline is a long path that starts with an initial three years of undergraduate studies, followed by a minimum of four years of postgraduate studies, before possibly entering an academic position (this is without considering possible postdoctoral positions). On entering an academic position additional skills are required; not only research skills, but also learning and teaching capabilities, including supervising skills for the masters and doctoral levels. In an ideal world, young academics should enter an encouraging and enabling environment which stimulates and nurtures the academic within them. Entering an environment which is not only pressurised and high paced, but with the workload often negatively skewed towards the younger staff, and without sufficient mentorship, often results in the loss of these young academics to the corporate world.

A lack of human capital and intellectual investment from academia will, and is, having a knock-on effect. Academic Statistics is already experiencing capacity issues, with a lack of experienced mid to late-career academics to train doctoral students and new doctoral graduates.

Informal discussions among the authors of this paper, all of whom are early to mid-career academics at South African institutions, have highlighted a general frustration amongst existing staff on several issues contributing to insecurity and uncertainty. These include, among others, insufficient training and mentorship to undertake masters and doctoral supervision, teaching and learning 'burnout', the general lack of prospects for permanent appointments, unclear understanding and inconsistency of promotional criteria for career growth, and establishing a work-life balance. In 2002 the lack of faculty positions was already evident in academia in the USA; see [29]. In [11], the work-life interferences in early-career Italian academics is discussed, highlighting the uncertainty due to contracts,

[1]HEMIS data, https://www.heda.co.za/PowerHEDA/dashboard.aspx, last accessed 13 April, 2022.

etc. In our discussion, it is clear that some universities allow for contract positions. These do not, however, provide employment benefits and are not automatically renewed, resulting in low job security and motivation compared to permanent academic positions in South Africa. Further investigation is required to understand the extent to which various departments rely on these non-permanent positions, and if the perception of the lack of permanent career growth opportunities in academia is justified or not. Keep in mind, however, that similar concerns are echoed in [11], with a particular emphasis on the differences between genders.

While it is true that good academics attract good students, this works in the other direction as well, with good students making learning and teaching, and research supervision, more fulfilling. However, to attract the best students, one needs to showcase research capabilities that are contemporary and cutting-edge. This means that academic staff must be visibly publishing on relevant topics, in higher-rated journals, with recognised collaborators in the field. This in itself is a process that takes time. An academic who is in sync with contemporary developments in the field will also naturally introduce such topics in class. However, as discussed already, this takes time, motivation, mentorship, and opportunities to showcase the research done with co-authors and with students at conferences. There is no doubt that prospective students who foresee research being peer-reviewed and published early on, are more likely to consider a career in academia.

As such, effective supervision largely drives the quality and success of graduates in postgraduate education; see [31]. However, given that successful supervision is a two-way process, with the core being the understanding between the supervisor and student's expectations and goals, the lack of experience among young supervisors may result in incorrect or unrealistic expectations to effectively guide the student. This may lead to a thesis that is not up to the standard required by the thesis examiners. In addition, there is no agreed upon or standard reference available on how to effectively supervise a PhD thesis in the Mathematical Sciences in South Africa and on how to prepare this thesis to be assessed, both of which can be relative and subjective. While there is substantial literature on how to effectively supervise postgraduate students in various fields, see [19, 31, 33], what is considered effective supervision is largely based on the institution's own vision, mission, values and research outputs; see [23]. In addition, the way in which a supervisor guides and interacts with their postgraduate student may be driven by their own experience and knowledge, which may itself be a product of poor supervision; see [31].

In terms of the examination of a PhD thesis, the parent institution usually provides the examiners with standard thesis examination guidelines. However, these guidelines can be very general, and may not be specific to the discipline. This can result in the examiner being idiosyncratic, resulting in discrepancies in the results and feedback of the examiners. All of these factors pose challenges to the success of a PhD student, and also to the final outcome of the examination process.

In this paper, we present a discussion of one possible solution path to the situation of doctoral supervision and thesis examination in academic Statistics in the absence of senior mentorship; a solution that has the potential to encapsulate and guide the entire doctoral journey and the relationship between supervisor and student.

3 Discussion

Given the background concerning the crises in academic Statistics in South Africa, the authors of the paper have met regularly over the last two years to discuss matters related to the nurturing and development of early-career Statistics PhD supervisors across South Africa. We present these discussions in the following order: the identity crisis of Statistics; funding a PhD; the thesis document; supervisor-student relationship; and, standardising assessment.

3.1 The identity crisis of statistics

A well accepted definition of Statistics is that of a discipline that concerns the collection, organisation, analysis, interpretation, and presentation of data. In [6] it is stated that "Definitions of statistics abound but many fail to capture adequately the essential interplay of data and theory. It is argued that the ubiquity of variability and uncertainty, which characteri[s]e a statistical problem, establish the subject as a major player in science and all rational enquiry". This perfectly captures the conundrum of a researcher in the Statistics discipline. Researchers will find themselves conducting core statistical research in order to graduate with a masters and doctoral degree in Statistics. However, having been trained as a statistician, the role in industry and in collaboration with other disciplines in academia, becomes one of application. While this is essential to develop further experience, and promotes growth of the discipline by highlighting areas in which new core statistical methods can be developed, the interpretation of the Statistics discipline by non-statisticians is often one of pure implementation. This further misleads graduates pursuing postgraduate studies into believing a data analysis study will produce a masters or doctoral study. The discipline thus suffers from an identity crisis.

The importance of a sustainable output of postgraduates in Statistics has already been highlighted, thus this identity crisis must be harnessed rather than dismissed. Core research in Statistics should advance the field. This can be achieved by theoretical building blocks, but also alternatively through an application focused on a trans-disciplinary problem needing the development of a new Statistical methodology.

Operations Research and Data Science add more layers to this identity crisis. Both have obvious statistical methodologies as backbone, but focus on different end-goals. Operations Research applies Statistics for decision-making, and is naturally more directed towards solving industry problems, although not without new methodology development for new problems. The definition of Data Science is controversial, with differences in opinions stemming from the home-discipline of the researcher or practitioner. Data Science is recognised as interdisciplinary, and aims to use techniques from Statistics, Mathematics and Computer Science to extract knowledge from complex data. It has gained momentum due to the vast amounts of data both accessible and collected by automated mechanisms. A trans-disciplinary set of skills thus becomes essential when dealing with such data – technological skills become as important for data-handling as statistical skills are important for data analysis and interpretation.

As with all disciplines, one has to remain trained through changing environments and changing needs. Society is a data generator, thus analytical skills are a basis for any

intention of scientifically understanding societal challenges. The need for analytical skills is thus evident, but the decision on where the research of a postgraduate student should aim to fit in, is multi-faceted.

The South African Council for Natural Scientific Professions[2] is the legislated regulatory body for Natural Science practitioners in South Africa. The body's mandate is for natural sciences, encompassing a wide range of scientific fields covering all of the basic sciences and many of their applied derivatives. The faculty in which a Statistics graduate completed causes an identity issue here as well. For example, a graduate with a BCom degree in Statistics will not identify as a Natural Scientist. Thus, a body such as SACNASP plays an essential role, ensuring constant training and an up-to-date skill set.

A prospective doctoral student has a variety of choices in South Africa when picking a discipline, institution, and supervisor. The choice may not be obvious, unfortunately, and becomes clearer the longer a student pursues postgraduate studies. A doctoral student who stays in academia needs to have been made excited about the discipline through their studies. Exposure to what Statistics is and what a career in Statistics involves, needs to be covered from the first year of study already. It is essential that academic Statisticians market themselves and not allow the identity crisis to overwhelm our discipline. The appreciation of a doctoral graduate has been taken up by industry as well, recognising their problem-solving abilities. The graduate should be developed into a highly skilled and versatile researcher that can interact in both academic and industry settings; see [41].

Two common reasons why attracting students into PhD programs has become difficult today follow. *First*, the fast-paced world of technology is to blame. With the advent of telemetry data, there is a growing need for Data Science and Data Engineering skills. The increasing demand for such skills is just one of the reasons why students are curious about more than just statistics. Thus, an increasing number of students who are more curious about how Facebook decides which newsfeed to show, or how Netflix decides which movies to recommend, find themselves re-purposing their core skill to "what may be more fascinating" today.

Skills demand generally translates to good pay and better job satisfaction as a means of retaining talent. A PhD in Statistics is at most the opposite of this. We, therefore, have a growing need to transform our programs and grow strong relations with industry.

Ultimately, even though a Statistics graduate may have progressed from a variety of home grounds of Statistics, the final outcome of a Statistics qualification should be uniform in its basic principles and objectives met. We may acknowledge and even utilise the disparate backgrounds that Statisticians come from, but as academia within Statistics we should aim to assure the quality of any Statistics-based thesis and graduate. Towards the end of the discussion we suggest a method that may assist in doing this; one that is clear from the start of the doctoral journey, and one that will help unify the outcomes of a Statistics degree, regardless of the identity of the journey taken up to and during the PhD study.

[2] `https://www.sacnasp.org.za/`

3.2 Funding

Once a prospective doctoral student has a clear idea of the doctoral thesis plan, funding for the duration of the study is required. Many doctoral students study while working full-time in industry, and some while lecturing. This is seemingly unavoidable due to the timing of doctoral studies, as the candidate will usually be between 25-35 years old and unable to be supported by parents. In addition, in South Africa, many graduates are the first in their families to obtain a university degree and are expected to work and provide for the family that has supported them up until that point. Fortunately, the job prospects for a Statistics graduate are bright, due to the aforementioned growth in data analytics throughout various industries in recent times.

However, this was not always the case. In 1980 the American Statistical Association stated in [9] that "the opportunities for statisticians in industry have not yet been fully recognised". The sustainability of academic Statistics was not an issue then it would seem. These effects push a student away from academia and from pursuing postgraduate studies. Some disciplines, such as creative fields, see [17], have less industry pull, and maintain a healthy pipeline of postgraduate students more easily. Li *et al*, [34], closely examined the path of 7 STEM postgraduates with funding, concluding that scholarship grants transcend instrumentalism privileging workforce demands. The funding must, however, be competitive as well as reasonable to live off. Of course, funding in a developed country looks vastly different to that in a developing country like South Africa.

Funding discussions should take place between student and supervisor early on and regularly, as this is a common cause of drop-out. More than this, the skill of attracting funding is increasingly becoming a necessity for professional development, rather than something that is simply 'nice to have'. The funding one needs to be able to attract could be anything from simple funding applications for supporting a student, to a travel grant for a conference, to the more involved funding for long-term trans-disciplinary projects. Young academics may well be disheartened in the early stages of their career if their funding applications fail, not necessarily viewing these tedious processes as those where, in general, success rates are low and competition is high. While young academics are likely to be able to motivate their research idea and methodology, they are unlikely able to arrive at a realistic time-versus-budget-versus-outcomes balance, nor to be able to showcase their research networks, since these are yet to develop. A successful funding application takes time and patience, and with a mentor can not only be fruitful but also very enjoyable. Funding agencies will often give useful feedback to unsuccessful applications, and if they don't, young applicants must request it with the purpose of improving their future proposals. Young academics should ideally refer to a mentor as a sounding-board to discuss if a funding opportunity is worth the effort, and more importantly, if their proposed idea actually falls within the scope of the funding call. Young applicants should also learn to take the feedback received from application assessors as constructive input, rather than criticism.

Without a senior mentor, funding applications can be a daunting task, especially if the supervisor themselves is not familiar with funding application processes. Thus, there should be guiding principles in place to assist those PhD students and their supervisors that are unfamiliar with such applications. These guidelines can be built into those for the

outcomes of the degree and/or the thesis document. Additionally, the creation of a network for early career academics in Statistics, with regular discussions and collaborations, could be highly effective in providing a type of horizontal, non-hierarchical mentorship to learn the academic path, including sourcing funding.

3.3 The thesis document

The production of "significant and original academic contribution at the frontiers of a discipline or field", [48, p. 40], stands central to the conferment of any doctoral degree. In South Africa, under the National Qualifications Framework (NQF), the three doctoral programmes available to SET candidates are the traditional doctorates (for academia), professional doctorates (for industry and other professions) and publication-based doctorates, with only the traditional and publication-based programmes actively utilised; see [15].

The qualifications frameworks for Higher Education require doctoral candidates to demonstrate certain cognitive skills during the course of the degree. All of these skills culminate in the presentation of a written document, known as the thesis, demonstrating theoretical and practical knowledge, intellectual independence, critical thinking, systematic investigation, theorising, and cogent reflections. The traditional monograph remains the most popular style of thesis and consists of a collection of sequential chapters describing specific aspects of the research logically. The emergence of the publication-based thesis breaks this stock-standard format, yielding greater variation and freedom to the candidate. The publication-based thesis may contain introductory and concluding chapters explaining the research conceptually and the doctorality of the body of work, and in-between these, several peer-reviewed published or publishable works, *e.g.* journal articles, published conference proceedings and/or book chapters (see, for example, [40]). A third alternative is a hybrid between the monograph and the publication-based thesis; see [44].

Over the years, several studies investigated the advantages and disadvantages of these different formats; see [21]. In the end, the main drivers deciding the format of a doctoral dissertation remain institutional policies, field-specific practices and the preferences of the supervisor; see [21]. This same publication, [21], lists several questions both the candidate and supervisor can work through when considering a publication-based PhD. The careful consideration of these questions will provide both parties with a clearer, pedagogical-based understanding of what the right format for the candidate is to complete their studies in the minimum required time. The traditional doctoral degree is typically considered training for an academic career with a focus on high-quality research capabilities and contributions to academia. Many universities and faculties still opt for the submission of the full traditional thesis format from which one or more publications can be extracted.

Over the last few decades, the PhD by publication has become a popular alternative, consisting of either a stand-alone set of published/publishable articles or a "thesis" format containing the articles and narrative linking them. Following this alternative route has several disadvantages and advantages over the traditional format, especially in SET fields; see [4]. Potential disadvantages and reasons why students may be dissuaded from following the route of a PhD by publication are the potential for distraction from the

main body of research; publication in unaccredited or field-specific low impact journals; and publication for the gain of the student and/or supervisor; see [35]. In comparison, the advantages include requiring a student to strategise more deliberately in order to achieve the outcomes of multiple sequential publications within the required time period; quicker development of soft skills required during the publication process; multiple blind reviews before the final submission of the completed thesis for examination; and the active and more effective dissemination of research into the knowledge economy than an unpublished thesis. One significant advantage a PhD by publication can have is publication experience for a potential future academic supervisor – the academic becomes equipped for pursuing publications very early on; see [60].

We believe that it is important for students at the start of their doctoral studies to be well-informed concerning the thesis structure choices they will have to make for their degree. Once again, uniform, transparent guidelines should be in place for achievement of doctoral outcomes across the different types of thesis structures, so that supervisors and their students can make the right decisions for each doctoral study.

3.4 Supervisor-student relationship

A supervisor is primarily responsible for guiding the student in writing a high quality thesis, with emphasis being on assistance. Furthermore, the supervisor is the first person to read the student's work in progress and provide comments and feedback.

More formally, Pearson and Brew, [49], define supervision as the process by which a student develops into an independent professional researcher and scholar in their field, capable of adapting to a variety of research environments both in academia or industry. According to [42], supervisors' responsibilities include guiding, advising, ensuring scientific quality, and providing necessary emotional and psychological support. Additionally, Abiddin, [2], suggests that effective supervisors show concern for their students.

While supervisors are supposed to play a critical role in the supervision process, Mapesela and Wilkinson, [39], discovered that many of them lack the institutional capacity to nurture. Some postgraduate students express frustration with their supervisors. The literature on supervision demonstrates that positive relationships are associated with academic success and student satisfaction; see [14, 37]. Abiddin, [2], argues that both the research student and the supervisor need clearly delineated tasks during the course of the supervision. Both supervisor and student should do their jobs effectively to maintain a good working relationship, but [2] further mentions that this will depend on the personalities involved as well as differences in disciplinary approaches to learning an teaching and the various learning tasks students are confronted with.

Cekiso *et al*, [13], found that most discouraged postgraduate students often complain about their supervisors being unavailable, by e-mail or by phone, and about having to pursue their supervisors all the time. However, effective supervision is not a one-way street; it is also dependent on the student's efforts to maintain a positive relationship. The *first* and most important requirement is that the student takes appointments seriously, arrives on time, and brings something to discuss. Supervisors are often far too overworked to deal with late cancellations or appointments that are rendered meaningless due to inaction.

Second, the supervisor can anticipate the student taking their advice seriously, all the more so when they have gone to great lengths to obtain it. The relationship can be transparent through an annual memorandum of understanding (MOU), which some institutions or Statistics departments in South Africa have in place. MOUs may be viewed as superficial by some, with the importance of a well-matched supervisor and student superceding the importance of the MOU. We believe that a collegiate relationship can be focused with a common, transparent, and well-defined goal.

Doctoral supervision is often conducted in teams, especially when topics are trans-disciplinary, requiring the presence of one or more co-supervisors to assist the student in specific topics of their research. For young supervisors, co-supervision is not just teamwork but a way to increase their networks and improve skills such as self-confidence, professional practice, and building an academic curriculum. Curriculum construction is an essential part of career progression, and supervision, even via co-supervision, benefits not only an early-career academic's curriculum vitae (CV) but also consolidates research groups and retains researchers; see [26, 43]. Co-supervision, in the construction of the curriculum, should be approached openly, that is, across departments and other institutions. As long as communication, discussion and planning take place in an articulated way for the benefit of the student, a team of researchers is beneficial to the student; see [47]. Usually the team will have at least one experienced supervisor, which will increase the likelihood of obtaining funding; see [30].

As discussed before, with limited access to experienced researchers the early-career supervisor in Statistics need an alternative support structure. In South Africa, the University of South Africa (UNISA) has a program for early-career supervisors, which has helped to improved both supervisory skills and other skills such as personal organisation, planning, leadership, and the decentralisation of learning support; see [59]. Programs like that offered by UNISA allow the development of universities, help young PhD students form curricula, and help increase the capacity for supervision of postgraduate courses and research.

South African higher education does not have sufficient production of high skills; see [32]. Academics who find it difficult to build a CV have poor results in research and innovation, have low morale and self-esteem and often resign their positions to move to institutions that pay better salaries after obtaining their PhD, even perhaps to industry. Therefore, a supervision team improves professional development of a supervisor and keeps supervisors motivated in their academic careers. A network of early-career academics could be an effective substitute.

Doctoral supervision entails a great deal of administrative tasks. Such tasks include assisting the student with their initial research proposal and application into the programme. Additional administrative tasks may entail establishing a MOU as well as submitting regular progress reports required by the university during the course of the doctorate. Prior to a student submitting their thesis for examination, the supervisor is responsible for registering the thesis title and nominating examiners for the thesis. In South Africa, the examination panel for a doctoral thesis usually consists of three independent examiners, where at least two examiners are external to the university. A further requirement may include at least one of the external examiners being based

internationally. The supervisor is responsible for obtaining the examiner's consent to be nominated along with their CVs. Following this, the supervisor submits a range of forms with all the details of the student and examiners to the appropriate university office. In the case where the co-supervisor of the doctoral student is young and still developing as a supervisor, these administrative tasks may fall to them, with the guidance of the main supervisor. While such tasks may be overwhelming at first for the young co-supervisor, it provides them with an opportunity to learn the university processes regarding doctoral supervision and examination. For a co-supervisor that may be on contract rather than permanent employment at the university, these administrative tasks can contribute towards their experience and track record, thereby providing them with an advantage should they apply for a permanent position in future.

Of course, all of this assumes that supervisors have sufficient mentorship to undertake these administrative tasks with the required assistance. Once again, a network of early-career academics could serve as an effective substitute, while a transparent set of guiding principles could aid in ensuring these tasks are completed on the required timeline.

3.5 Standardising assessment

3.5.1 Assessment needs

There is an argument to be made that assistance, training, and/or standardisation in assessment will ease the burden placed on early career supervisors while maintaining high standards of postgraduate research.

It is accepted that assessment in higher education should be, valid, reliable, fair, and transparent, that assessment should also be aligned with the outcomes of the course/module, programme or degree, and ultimately, that assessment should be integrated within these so as to be able to improve learning. In the context of postgraduate research, we still seek all of the above characteristics for assessment, although the improvement of learning is achieved not so much through formative methods, but rather primarily through transparency in the summative assessment process.

Within Statistics in South African higher education, we suggest that there is an additional need to ensure that the required assessment practices are sustainable, not only within a single institution, but within Statistics country-wide. With the difficulties associated with the pull of industry away from academia, and the comings and goings of senior research supervisors, we should strive to guarantee the transferability of high quality research postgraduates between academic institutions as well as collaboration between institutions.

The assessment instrument that this paper proposes development of, will always remain the same – a research output in the form of a written thesis. It is the assessment method and tool that this paper suggests engaging with, namely the development and implementation of a standardised rubric that can be used throughout postgraduate research qualifications in Statistics.

3.5.2 Rubrics

Assessment rubrics are cross-tabulations of assessment criteria against assessment standards; see [54]. A 'rubric' in an academic context has been defined as "a scoring tool that lists the criteria for a piece of work or 'what counts' "[3]. The effectiveness of a rubric therefore lies in being able to define the context on which the said rubric will be used, by whom and to what end, and in this context, it should aim at providing both the student and the supervisor with a reasonable scope that is defined in writing, and in which the notion of 'quality' within their scope of engagement has also been defined[4]. A rubric generally provides gradations of quality for each criterion that can be monitored by both the student and the supervisor. From the student's perspective, it provides a written reference of what is expected, and from the (early career) supervisor's perspective not only saves time, but can also provide a uniform basis of engagement with multiple students. However, while rubrics can be great as a template for progress, a badly defined rubric can defeat the purpose entirely, and hence "issues of validity, reliability, and fairness apply to rubrics too"; see [3, p. 29]. Furthermore, the intended effectiveness of the rubric needs to be evaluated regularly and updated as necessary.

The benefits of a rubric within an academic context have been well documented; see [3, 50]. Research on the use of rubrics for analytic (as opposed to holistic) assessment in higher education is extensive (see, e.g., [54] and the references therein). The use of rubrics, or analytic assessment, is considered better practice than assigning an overall grade or holistic assessment, although there is some support for the latter. Within the wider topic of rubrics for assessment in higher education, research has been completed on the creation and use of rubrics for research items that serve as capstones for coursework degrees, see, for example [51, 57, 58], although research on rubrics used for postgraduate dissertations or theses is scarce.

Rubrics are often used as part of formative assessment, and for this reason their effectiveness is dependent on their connection to self and peer assessment, see, e.g., [52], as well as the extent to which students understand the jargon used in the rubric. For our purposes, however, a rubric for a research thesis would be primarily for summative assessment, with the main purpose being the promotion and maintenance of reliability in assessment and the transferability of students across institutions. In other words, the type of rubric that this paper suggests creating is one that focuses exclusively on the research product, in contrast to holistic grading that integrates product and process; see [58]. [51] developed a rubric for the capstone research project for an undergraduate degree based on the manual of the American Psychological Association (APA). The authors suggest that adequate organisation is key to the effectiveness of the rubric, although we feel that this is only the case if rubrics are used for formative assessment, something we would be avoiding. However, we mirror the authors' sentiments when they suggest that the rubric should be constructed within the mindset that students struggle to know what is expected of them in producing a research output, that students must learn to make holistic judgements where multiple criteria are attended to simultaneously, and that students struggle to understand

[3] https://www.csuchico.edu/assessment/_assets/documents/andrade-teaching-with-rubrics.pdf

[4] https://www.uen.org/rubric/know.shtml

abstract criteria.

A rubric should thus be constructed with simplicity in mind. We recommend the addition of a holistic dimension to the rubric (being careful not to double-count), since this is important in student development at this level; see [54]. Finally, it is worth noting that the rubric in [51] is aimed at quality enhancement rather than assurance, while we are only concerned with the latter. It can, of course, be argued that a transparent set of assessment criteria and associated levels of achievement lead naturally to quality enhancement. The research behind the use of rubrics in higher education is extensive, but this paper will only touch on how an assessment rubric can help to solve some of the problems in postgraduate supervision within Statistics that have been identified, namely strengthening interactions within Mathematical Sciences (from [1]), improving transparency (from [61]), and lessening the assessment burden of under-experienced junior supervisors (from [10]). Moreover, it is also important to mention the strengthening of consistency in assessment that rubrics bring with them.

3.5.3 Rubrics as problem-solvers

As academic assessors, we use rubrics (and analytic assessment) so that students are informed of what they need to do for a particular assessment task, so that grading processes for the task are transparent, defensible, and more fair, and because systematised approaches are more efficient. These very purposes of a rubric - those of transparency and efficiency - directly align with two of the problems in postgraduate supervision that this paper has identified, namely the improving of transparency and the reduction of assessment burden on early career supervisors. For a thesis student, a rubric can provide well-defined goals at the start of the PhD journey, and can guide the supervisor as well as student as to what the expectations and goals are for a successful, high-quality thesis.

While on the topic of transparency, the idea of consistency should be considered, since the former leads naturally to the latter when fairness is an underlying principle. The use of a rubric, a transparent set of assessment criteria, can ensure more consistency among the examiners as well as more consistency in the standard of PhD theses across South Africa; it can reduce the subjectivity of the examiners by providing some common-minimum expected quality. In the case where the supervisory team consists of more than one supervisor, the rubric can assist in ensuring that all of the supervisors are on the same page with regard to the expectations, goals and quality of the thesis, which is especially important when the supervisors come from different fields, backgrounds, and experience. This is especially important for Statistics, where supervisors (and indeed assessors) often come from fields outside of 'core' Statistics, since statistical methods are often developed or advanced in a Statistics thesis for use in a particular ancillary field. Note also that consistency in theses implies consistency in the quality of graduates as well, ensuring that PhD graduates are more transferable across institutions after their studies. As discussed previously, this will help to solve the identity crisis in Statistics.

While rubrics are traditionally only used for assessment, we feel that the guiding principles for funding applications and administrative tasks, as well as the MOU between student and supervisor and the arrangement between teams of supervisors can be incorporated into the rubric. The rubric need not be used only for assessment of the thesis and the

PhD candidate, but the process itself and the tasks required to be undertaken by the supervisors.

It is expected that in the process of creating standardised rubric for postgraduate Statistics research outputs would stimulate debate between Statistics departments in South Africa with regards to thesis learning outcomes, and would advertise what it is that Statistics departments are seeking when asking students to do postgraduate research. There is no doubt that any collaborative process between Statistics departments in South Africa to set forth agreed-upon guiding principles for an assessment rubric will strengthen the ties between participating departments. Finally, no rubric is etched in stone, and in fact must be reassessed over time.

3.6 Supervisor growth

The growth of a supervisor starts with building a CV as an academic and early-career researcher. In South Africa in general, when building an academic CV, one has to concentrate on two main themes, namely learning and learning (L&T), and research and innovation. L&T mainly involves the teaching of core modules and courses in Statistics at both one's resident institution of higher learning and other external institutions by invitation, but also includes the development of course materials and being actively involved as an external examiner of modules and courses internally and externally. Research and innovation involves the writing of journal articles for publication and attending national and international conferences in one's field of special interest. At most institutions, the research leg of CVs includes the supervision of postgraduate students, mainly doctoral (PhD) students, but at some this also falls under the scope of L&T.

In the pursuit of supervision growth, it is important to observe research ethics and integrity within supervision and publication of journal articles. A widely used and universally endorsed research ethics and integrity statement with comprehensive and clear principles and responsibilities is the Singapore Statement on Research Integrity[5]. In more detail, the four principles of the Singapore Statement are: "honesty in all aspects of research; accountability in the conduct of research; professional courtesy and fairness in working with others; and good stewardship of research on behalf of others" (World Conference on Research Integrity, 2010[6]; see [53]).

Supervisor growth requires the early-career researcher to join research groups and work on building a team of collaborators. This helps in sharing new ideas about supervision, problems encountered in supervision, ethical issues involved in supervision, and sharing of diverse research expertise, assisting the early-career supervisor to develop into an experienced supervisor in Statistics. The need for collaboration is also necessitated by the fact that most experienced supervisors in the field of Statistics are either retired or past retirement age. If supervision networks cannot be built with these senior academics, at least providing an opportunity for early-career supervisors to join together will allow for sharing of supervision styles and skills.

[5]World Conference on Research Integrity, 2010; `https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3954607/#R7`

[6]https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3954607/R7

Supervision of postgraduate research studies draws on a wide range of experiences, personality traits, management skills, leadership styles, various L&T theories, research expertise, research ethics and integrity. Gatfield, [22]), and Deuchar, [18], proposed a dynamic conceptual model for PhD supervisory styles, categorising PhD supervisory styles into four themes, namely *Laissez-Faire*, pastoral, directorial and contractual styles. These four supervision styles are defined by the amount of support and structure involved in the supervisory grid; see [18, 22].

The *Laissez-Faire* style is characterised by the following attributes: low structure and low support; candidate has limited levels of motivation and management skills; supervisor is non-directive and not committed to high levels of personal interaction; and, supervisor may appear uncaring and uninvolved. On the other hand, the pastoral style is characterised by low structure and high support; candidate has low management skills but takes advantage of all the support facilities that are on offer; and supervisor provides considerable personal care and support but not necessarily in a task-driven directive capacity. The directorial style is characterised by high structure and low support; candidate is highly motivated and sees the necessity to take advantage of engaging in high structural activities such as setting objectives, completing and submitting work on time on own initiative without taking advantage of institutional support; and, supervisor has a close and regular interactive relationship with the candidate, but avoids non-task issues. The fourth style on the supervisory grid, the contractual style, is characterised by high structure and high support; candidate is highly motivated and able to take direction and to act on own initiative; supervisor is able to administer direction and exercises good management skills and interpersonal relationships; and most demanding in terms of supervisor time; see [18, 22].

The diversity in supervision styles makes co-supervision of PhD studies important. When supervisors are collaborating in supervision at a horizontal level they can share their supervision experiences gained on the field or gained from their doctoral studies with their mentors. When collaborating with experienced supervisors, the experienced supervisor who is the mentor will transfer the supervision skills to the early career supervisor who is the mentee. The skills from experienced supervisors may also include such skills as how to attract students for PhD studies and assisting students with grant proposals so that they can continue with their studies without much stress related to funding their studies and conference attendances. In the absence of this mentoring, it is vital to understand that this development still needs to take place - meaning that a collaborative inter-institution group may be necessary to provide the necessary network.

Another aspect important in supervision growth is working towards NRF rating, a task dedicated to developing a research career specialising in a particular field of interest in Statistics in South Africa. When the early-career supervisor is not working towards an NRF rating, they tend to diversify the supervision research topics and even their journal publications will not be in any specialised statistics field of interest. An early career supervisor needs to be aware that their supervision growth needs to be tailored into a specific Statistics field of interest in order to gain an NRF rating.

Supervision growth should also include serving in the role of external assessor/examiner for both master's and PhD studies. In serving as an external examiner, one gains experience in the examination process of theses/dissertations, as well as gaining exposure

to other institutions' preparation used for their PhD studies. In doing so, the early-career supervisor will improve their supervision skills and possibly diversify their supervision approaches. Another reason for serving as an external examiner is academic citizenship – it is easy to imagine that if one declines to serve as an external examiner or assessor for other institutions, one should expect the same from these academics in return when asking them to serve in a similar capacity.

4 Conclusion

This discussion has many components that could be further highlighted with respect to doctoral supervision in Statistics, and general capacity development in academic Statistics in South Africa. We have focused on a possible solution to the most serious hurdles in postgraduate Statistics research supervision, a guiding rubric in conjunction with an active network of early-career academic Statisticians. Indeed such an idea, although with a simpler required outcome, is discussed in this paper in Nature[7] on networking during the COVID-19 pandemic.

The authors aim to implement this strategy of a guiding rubric and network by engaging with the senior professors in the community as a first step. The group will seek guidance on the rubric elements that should be implemented – elements that have been identified in this paper, and others that may have been missed – in order to (1) unify the identity of Statistics across institutions, (2) encourage high-quality funding applications, (3) develop an efficient supervisor-student team, (4) quantify and qualify the thesis assessment criteria, and (5) encourage the horizontal development of an early-career supervisor into a well-connected and experienced mentor. Further involvement between Statistics departments within South Africa will provide insight into the varying needs of both small and large, and both developed and developing departments, towards a guiding rubric that is useful to all. An enormous benefit of such a rubric would also be to provide basic assessment principles for Statistics, which could additionally be extended down the academic pipeline to the undergraduate level. This can all be achieved without the direct, imposing evaluation or audit of departments.

Initial discussions with a number of departments have persistently brought up the difficulty of transferring between institutions and the 'silo' type of research activity that exists, where departments isolate themselves in their research fields. While there are many instances of international collaborations, collaborations between Statistics departments in South Africa are less prominent. The advantages stemming from moving online since 2020 can easily be harnessed to alleviate this isolation, and to aid in developing an early-career supervisor network. In exactly this manner, the authors have held discussions since 2020; discussions that have led to this paper and that have effectively allowed the group to mentor each other during this time. The logical next step is the extension of these ideas more broadly to South African Statistics departments. All experiences by academic Statisticians are valid and contribute in some way to the sustainability of Statistics; a goal which is not negotiable.

[7] https://www.nature.com/articles/d41586-020-02159-x

References

[1] 2013. *Mathematical Sciences in 2025.* National Research Council, The National Academies Press, Washington D.C.

[2] Abiddin, N. 2007. *Postgraduate students'perception on effective supervision: A case study at one public university in Malaysia.* Journal Of International Social Research, 1(1).

[3] Andrade, H. 2005. *Teaching with rubrics: The good, the bad, and the ugly.* College Teaching, 53(1): 27–30.

[4] Asongu, S. & Nwachukwu, J. 2018. *PhD by publication as an argument for innovation and technology transfer: With emphasis on Africa.* Higher Education Quarterly, 72(1): 15–28.

[5] Barnes, B., Williams, E. & Stassen, M. 2012. *Dissecting doctoral advising: A comparison of students' experiences across disciplines.* Journal of Further and Higher Education, 36(3): 309–331.

[6] Bartholomew, D. 1995. *What is statistics?* Journal of the Royal Statistical Society, 158(1): 1–20.

[7] Biglan, A. 1973. *Relationships between subject matter characteristics and the structure and output of university departments.* Journal of Applied Psychology, 57(3): 204–213.

[8] Blom, A., Lan, G. & Adil, M. 2015. *Sub-Saharan African science, technology, engineering, and mathematics research: A decade of development.* World Bank Publications.

[9] Boardman, T., Hahn, G., Hill, W., Hocking, R.R., Hunter, W., Lawton, W., Ott, R., Snee, R. & Strawderman, W. 1980. *Preparing statisticians for careers in industry: Report of the ASA section on statistical education committee on training of statisticians for industry.* The American Statistician, (2): 65–75.

[10] Botha, M. & Prinsloo, P. 2008. *The crisis in academic statistics: An exploration.* Africa Education Review, 5(2): 169–183.

[11] Bozzon, R., Murgia, A., Poggio, B. & Rapetti, E. *Work–life interferences in the early stages of academic careers: The case of precarious researchers in Italy.* European Educational Research Journal, 16(2-3): 332–351.

[12] Carlson, M. 1999. *The mathematical behavior of six successful mathematics graduate students: Influences leading to mathematical success.* Educational Studies in Mathematics, 40(3): 237–258.

[13] Cekiso, M., Tshotsho, B., Masha, R. & Saziwa, T. 2019. *Supervision experiences of postgraduate research students at one South African higher education institution.* South African Journal of Higher Education, 33(3): 8–25.

[14] Chireshe, R. 2012. *Research supervision: Postgraduate students' experiences in South Africa.* Journal of Social Sciences, 31(2): 229–234.

[15] Cloete, N., Mouton, J. & Sheppard, C. 2015. *Doctoral education in South Africa.* African Minds.

[16] Commission, N.P. 2012. *National development plan 2030. our future - make it work.* Report 1-484, National Planning Commission.

[17] Comunian, R., Faggian, A. & Jewell, S. 2011. *Winning and losing in the creative industries: An analysis of creative graduates' career opportunities across creative disciplines.* Cultural Trends, 20(3-4): 291–308.

[18] Deuchar, R. 2008. *Facilitator, director or critical friend?: Contradiction and congruence in doctoral supervision styles.* Teaching in Higher Education, 13(4): 489–500.

[19] Dietz, A., Jansen, J. & Wadee, A. 2006. *Effective PhD Supervision and Mentorship: A workbook based on experiences from South Africa and the Netherlands.* Rozenberg Publishers (Amsterdam) - UNISA Press (Pretoria).

[20] Duffin, J. & Simpson, A. 2005. *Cognitive empathy and the translation to independent graduate study in mathematics.* Educational Studies in Mathematics.

[21] Frick, L. 2019. *PhD by publication–Panacea or paralysis?* Africa Education Review, 16(5): 47–59.

[22] Gatfield, T. 2005. *An investigation into PhD supervisory management styles: Development of a dynamic conceptual model and its managerial implications.* Journal of Higher Education Policy and Management, 27(3): 311–325.

[23] Grant, K., Hackney, R. & Edgar, D. 2014. *Postgraduate research supervision: An 'agreed' conceptual view of good practice through derived metaphors.* International Journal of Doctoral Studies, 9: 43–60. doi:https://doi.org/10.28945/1952.

[24] Grevholm, B., Persson, L.E. & Wall, P. 2005. *A dynamic model for education of doctoral students and guidance of supervisors in research groups.* Educational Studies in Mathematics, 60(2): 173–197.

[25] Hancock, S. 2019. *A future in the knowledge economy? analysing the career strategies of doctoral scientists through the principles of game theory.* Higher Education, 78(1): 33–49.

[26] Hassan, S., Barnes, K., Price, M., Gumedze, F. & Morrell, R. 2019. *Academic promotions at a South African university: Questions of bias, politics and transformation.* Higher Education, 78(3): 423–442.

[27] Hassani, H., Beneki, C., Silva, E., Vandeput, N. & Madsen, D. 2021. *The science of statistics versus data science: What is the future?* Technological Forecasting and Social Change, 173.

[28] Herzig, A. 2002. *Where have all the students gone? participation of doctoral students in authentic mathematical activity as a necessary condition for persistence toward the PhD.* Educational Studies in Mathematics, 50(2): 177–212.

[29] Huisman, J., de Weert, E. & Bartelse, J. 2002. *Academic careers from a European perspective.* The Journal of Higher Education, 73(1): 141–160.

[30] Hulteberg, C., Isaksson, H., Rodrigues, J., Rusek, D. & Sohl, C. 2011. *Developing independent as young academics at lth.* Docentkurs vid LTH, 1(1): 1–13.

[31] Igumbor, J., Bosire, E., Karimi, F., Katahoire, A., Allison, J., Muula, A., Peixoto, A., Otwombe, K., Gitau, E., Bondjers, G., Fonn, S. & Ajuwon, A. 2022. *Effective supervision of doctoral students in public and population health in Africa: Carta supervisors' experiences, challenges and perceived opportunities.* Global Public Health, 17(4): 496–511. doi:10.1080/17441692.2020.1864752. URL `https://doi.org/10.1080/17441692.2020.1864752`. PMID: 33351732.

[32] Jili, N. & Masuku, M. 2017. *Supervision as a tool of producing independent researches: Reflecting on supervision processes.* International Journal of Sciences and Research, 8(73): 339–350.

[33] Lee, A. 2007. *Developing effective supervisors: Concepts of research supervision.* South African Journal of Higher Education, 4: 680–693.

[34] Li, J., Craig, C., Gale, T., Norton, M., Zhu, G., Evans, P., Stokes, D. & Verma, R. 2021. *Preparing Teachers to Teach the STEM Disciplines in America's Urban Schools (Advances in Research on Teaching, Vol. 35)*, Emerald Publishing Limited, Bingley, chap. The Value of STEM Scholarship Grants to Undergraduate and Graduate Students Intending to Study the STEM Disciplines and Pursue STEM Careers, 179–200.

[35] Li, Y. 2016. *"Publish SCI papers or no degree": Practices of Chinese doctoral supervisors in response to the publication pressure on science students.* Asia Pacific Journal of Education, 36(4): 545–558.

[36] Lindsay, B., Kettenring, J. & Siegmund, D. 2004. *A report on the future of statistics.* Statistical Science, 19(3): 387–413.

[37] Mainhard, T., Van Der Rijst, R., Van Tartwijk, J. & Wubbels, T. 2009. *A model for the supervisor–doctoral student relationship.* Higher education, 58(3): 359–373.

[38] Maor, D. & Fraser, B. 1995. *A case study of postgraduate supervision in a natural sciences department.* Tech. rep., Paper presented at the Annual Meeting of the American Educational Research Association, San Francisco, California.

[39] Mapesela, M. & Wilkinson, A. 2005. *The pains and gains of supervising postgraduate students from a distance: The case of six students from Lesotho.* South African Journal of Higher Education, 19(sed-1): 1238–1254.

[40] Mason, S. & Merga, M. 2018. *Integrating publications in the social science doctoral thesis by publication.* Higher Education Research & Development, 37(7): 1454–1471.

[41] Mitic, R. & Okahana, H. 2021. *Don't count them out: PhD skills development and careers in industry.* Studies in Graduate and Postdoctoral Education, 12(2): 206–229.

[42] Mouton, J. 2001. *How to succeed in your master's and doctoral studies: A South African guide and resource book.* Van Schaik.

[43] Mushemeza, E. 2016. *Opportunities and challenges of academic staff in higher education in Africa.* International Journal of Higher Education, 5(3): 1–11.

[44] Odendaal, A. & Frick, L. 2018. *Research dissemination and PhD thesis format at a South African university: The impact of policy on practice.* Innovations in Education and Teaching International, 55(5): 594–601.

[45] of Higher Education, D. & Training 2020. *Are we producing enough doctoral graduates in our universities?* Report 1-5, Department of Higher Education and Training.

[46] of Higher Education, D. & Training 2020. *Post-school education and training monitor. Macro-indicator trends.* Report 1-109, Department of Higher Education and Training.

[47] Olmos-López, P. & Sunderland, J. 2017. *Doctoral supervisors' and supervisees' responses to co-supervision.* Journal of Further and Higher Education, 41(6): 727–740.

[48] on Higher Education, C. 2013. *The higher education qualifications sub-framework.* Report 1-43, Council on Higher Education.

[49] Pearson, M. & Brew, A. 2002. *Research training and supervision development.* Studies in Higher education, 27(2): 135–150.

[50] Popham, W. 1997. *Consequential validity: Right concern-wrong concept.* Educational Measurement: Issues and Practice, 16(2): 9–13.

[51] Prins, F., de Kleijn, R. & van Tartwijk, J. 2017. *Students' use of a rubric for research theses.* Assessment Evaluation in Higher Education, 42(1): 128 – 150.

[52] Pui, P., Yuen, B. & Goh, H. 2021. *Using a criterion-referenced rubric to enhance student learning: A case study in a critical thinking and writing module.* Higher Education Research and Development, 40(5): 1056 – 1069.

[53] Resnik, D. & Shamoo, A. 2011. *The Singapore statement on research integrity.* Accountability in research, 18(2): 71–75.

[54] Sadler, D. 2009. *Indeterminacy in the use of preset criteria for assessment and grading.* Assessment & Evaluation in Higher Education, 34(2): 159–179.

[55] Smith, J. & Hungwe, K. 1998. *Conjecture and verification in research and teaching: Conversations with young mathematicians.* For the Learning of Mathematics, 18(3): 40–46.

[56] Smith, T. & Staetsky, L. 2007. *The teaching of statistics in uk universities.* Journal of the Royal Statistical Society: Series A (Statistics in Society), 170(3): 581–622.

[57] Trosset, C. & Weisler, S. 2014. *A cross-disciplinary approach to evaluating the senior thesis. (cover story).* Assessment Update, 26(6): 1 – 16.

[58] Trosset, C. & Weisler, S. 2018. *What makes a senior thesis good?.* Change: The Magazine of Higher Learning, 50(1): 47 – 53.

[59] van Jaarsveldt, L. 2010. *An evaluation of a developmental programme for young academics at the university of South Africa: Views from participants.* Commonwealth Youth and Development, 8(1): 102–114.

[60] Van Schalkwyk, S., Mouton, J., Redelinghuys, H. & McKenna, S. 2020. *A systematic analysis of doctoral publication trends in South Africa.* South African Journal of Science, 116(7-8): 1–9.

[61] Vekkaila, J., Pyhlato, K., Hakkarainen, K., Keskinen, J. & Lonka, K. 2012. *Doctoral students' key learning experiences in the natural sciences.* International Journal for Researcher Development, 3(2): 154–183.