International Educational Review
https://int-er.com

Towards an Integrated Model for Orienting Preservice Science Teachers for 21st-Century Teaching

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Abstract: This conceptual paper builds the case for orienting preservice science teachers for 21st-century teaching on a footing of Miller et al. (2013) framework for science teacher preparation called the Model of Research-Based Education for Teachers (MORE for Teachers). MORE for Teachers frames science teacher preparation as anchored on four pillars: in-depth subject matter, research-based science teaching methods, guided practicum, and a shared vision of the pedagogy of science learning. Based on the limitations of Miller et al.'s linear model yet still maintaining the value of its central tenets the paper proposes a model that is interactive and framing standards in science teaching, curriculum development, rigorous content, research-based science methods course, and quality field experiences as the essential aspects for producing teacher candidates with the right skills for science teaching. The paper argues that pre-service science teachers (PSTs) development in teacher education colleges and universities requires a framework for harmonization that ensures consideration of all the necessary ingredients for science teacher preparation. Drawing on a diversity of literature sources on science teacher education the paper discusses the application of the proposed model in Zimbabwe, illustrating the importance of detailed methods courses, rigorous science content, expert mentoring, personal teaching philosophy, and a consideration of international trends in science teaching. In conclusion, the paper recommends other contexts where the integrated model for science teacher preparation can be used and some steps for its practical implementation.

Keywords: integrated STEM teaching; integrated knowledge systems; hybrid laboratories; rigorous content knowledge; research-based science pedagogy

DOI: https://doi.org/10.58693/ier.311

Introduction

The growth of many national economies has been linked to developments in science and technology. “Science, technology, and innovation (STI) play a critical role in the socioeconomic development of a country” (Roopchund, 2023 p. 167). For that reason, nations have prioritized science teacher education because it is believed that well-trained science teachers are key to the success of science education in schools. The education of science teachers is a human resources development aspect mandated under higher education institutions. In Zimbabwe, science teacher development is done through teachers’ colleges and universities. Teachers’ colleges train science teachers for the award of a diploma in education under a scheme of association with the University of Zimbabwe (UZ). Content for the science education courses in these colleges is developed by lecturers. The Centre for Teacher Education and Materials Development (CTEMD) of the UZ provides oversight for all syllabus review processes. Despite slight variations, all science education courses in the colleges comprise four components- Academic Study (subject matter knowledge), Professional Studies (Methods of Teaching), Theory of Education (Educational studies in Psychology, Sociology, Philosophy, Management, and Curriculum), and Attachment Teaching Practice (Internship). In contrast, other universities, state and private, also develop mostly undergraduate pre-service and in-service science teachers guided by minimum bodies of knowledge (MBKs) prescribed by the Zimbabwe Council of Higher Education (ZIMCHE). A minimum body of knowledge seeks to achieve horizontal comparability of education and training by providing mandatory minimum knowledge competencies each degree or diploma course offers across institutions (Ministry of Higher and Tertiary Education, Science and Technology Development, 2018). However, there seems to be an absence of a national integrated model that harmonizes teacher development in education colleges and universities. In the current situation, a science teacher graduating with a diploma in teacher education from college might have completely different competencies for science teaching from their counterpart with a similar qualification from a university. This is because some crucial components of the Science Teaching Methods modules such as The Nature of Science (NOS), History and Philosophy of Science/Disciplinary teaching, Contemporary Trends in the teaching of disciplinary subjects (Biology, Chemistry, and Physics), science, technology, engineering, and mathematics/ science, technology, engineering, arts, and mathematics/ science, technology, recreation, engineering, arts, and mathematics (STEM/STEAM/STREAM) teaching approaches, and others that are usually regarded as indispensable to science teacher preparation programs are often left out in both or either setup (Mutseekwa, 2017). While public opinion may applaud the differences as expected based on the widely accepted perception of universities' superiority, teaching methods and cognitive skills such as logical abstract thinking, problem-solving, research, inquiry, and appropriate means of illustration and abstraction required for science teaching are the same regardless of where teacher candidates obtained their training, and more so when these two groups eventually teach the same students from the same schools (Yorkovsky & Levenberg, 2022).

This paper is guided by Miller's et al. (2013) framework for science teacher preparation called the Model of Research-Based Education for Teachers (MORE for Teachers). MORE for Teachers frames science teacher preparation schemes as anchored on four aspects; in-depth subject matter, research-based science teaching methods, guided practicum, and shared vision of the pedagogy of science learning (Miller et al., 2013). The thesis of this paper is centered on the notion that science teacher preparation is a complex phenomenon that calls for several integrated aspects. An integrated approach in this context brings together various approaches to the preparation of science teachers that have been advanced. There is thin literature that advances in detail the nature of integration needed for secondary school science teacher preparation. Carmi and Tamir (2022) posit that developing effective models is an ongoing challenge for teacher educators. This is because such frameworks and models need a balancing act between the content and pedagogy provision with field practice and professional growth requirements for individual students. The paper endeavors to answer the question; What integrated approach can be used to develop reform-minded teacher candidates with the right skills for science teaching?

The Dynamics of Teacher Preparation

The dynamics of teacher preparation have evolved over the last decade due to several global trends such as the advent of the digital age and the industrial revolution 4.0. These changes coupled with new socio-economic demands require teachers with new and specific skills. Previously, programs focused exclusively on knowledge-based teachers through intellectually-based models (Carmi & Tamir, 2022). Programs have shifted from purely academic to practical approaches involving teacher candidates in extended field experiences. Accordingly, such programs are gradually embracing goals that bring together theory and practice (Carmi & Tamir, 2022). In the USA science teacher preparation was designed to match the goals of secondary school science teaching. According to Morrel et al. (2020), this focus on secondary school teacher preparation evolved from the use of the 2012 Science Teacher Preparation Standards by the Council for Accreditation of Education Programs (CAEP) for accrediting teacher preparation programs. Some scholars have begun to argue for professionalized teacher education programs that involve three ideals. Drawing on Dewey, Elliot Eisner, and Zeichner's separate works, Carmi and Tamir (2022) propose preparation programs that embrace theoretical knowledge, practical know-how, creativity, and aesthetical literacy. In their view preparation of teachers focuses on three areas; teachers as intellectual, as craftsmen, and as artists respectively. In the teacher as intellectual, teaching is framed as a knowledge-based endeavor where teachers strive to abstract, theorize, and build a firm knowledge base for their profession while in the crafts person mode teaching is a practice-based venture in which the teacher is guided by a set of core practices that shape effective pedagogy (Carmi & Tamir, 2022). In the teacher as an artist, teaching is viewed as self-based. Implying that the teachers' practice is regarded as a creative process emanating from personal experiential learning. However, the authors quickly hint at the complexity of integrating the three ideals within the contemporary climate of teacher preparation.

In most African countries science teacher development is quintessential of their colonial masters. An almost similar curriculum is therefore observed in Zimbabwe, Malawi, Zambia, and Botswana because these countries were once British colonies. However, Ogunniyi and Rollnick (2015) note that on a general note science teacher preparation programs in Africa consist of education theory courses, science content, and methods courses taught to prospective science teachers with debate currently on the balance between these and how they should be taught. Parallels are drawn with science teacher development programs in China. Liu et al. (2015) aver that pre-service science teachers are required to take three types of courses, including general courses, professional courses, and teacher education courses to complete their training program. General courses are composed of arts and humanities subjects, professional courses are constituted by content subjects in the natural and earth sciences, while teacher education courses include the theory of education courses and professional studies. Both the African and Chinese programs have a practicum normally sandwiched between the duration of training. While commonalities and differences emerge in science teacher programs offered in Africa and Europe, Evagorou et al. (2015) observe three themes emerging from the latter, namely: some teacher training programs are placing an emphasis not only on pedagogy but on research as well, a balance between practice and theory is important during preparation and continuous professional development though essential, it is not compulsory. Finland's distinction is oriented toward practices emphasizing action research (Soprano & Yang, 2013). Evagorou et al. (2015 p. 114) say; "Finland emphasizes teacher preparation that considers research as important and encourages teachers to apply their research skills to explore the outcomes of their teaching. By emphasizing research, teachers are educated on how to research and improve their practice".

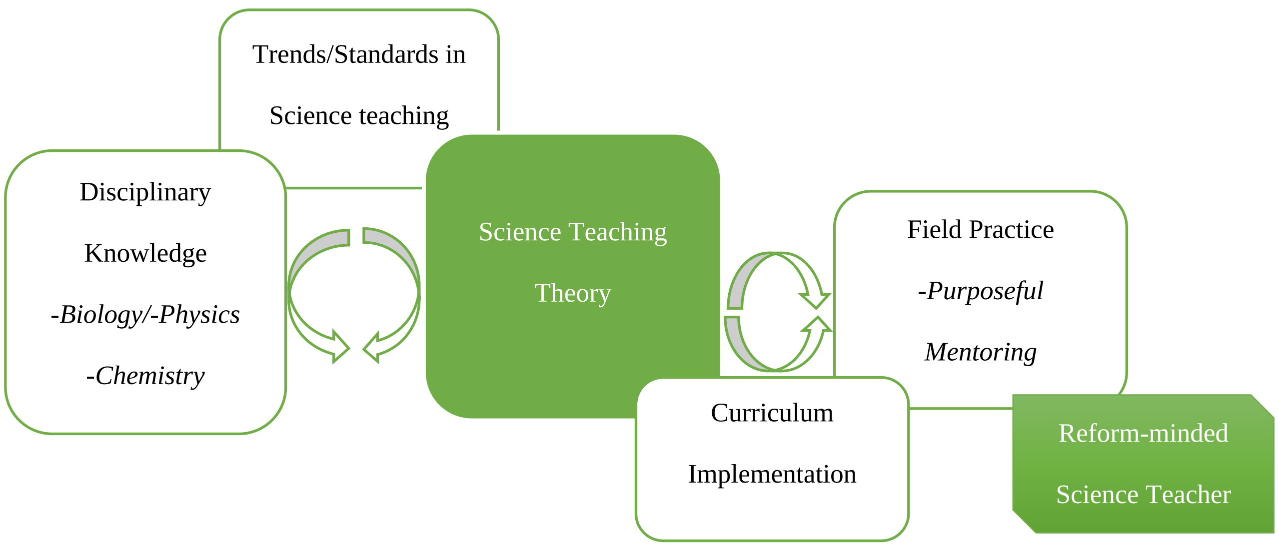
Towards an Integrated Model for Science Teacher Preparation

Prominent scholars on teacher preparation such as Darling-Hammond (2014) have identified six components of effective programs. Such components seem to be an attempt at crafting preparation programs that bring together the three models of the teacher as intellectual, as a craftsman, and as an artist. For instance, Darling-Hammond's (2014) framing of a common vision, standards that delineate expected practices, curriculum guidelines, field experiences, stakeholder involvement and collaboration, and teacher reflective practice are crucial features of a general teacher development program (Fullan, 2007). Despite being a general model that is not specific to science education, the emphasis in Darling-Hammond's (2014) components is on program coherence, students' application of educational theory into practice, and relationships that are cemented through common expectations, and shared beliefs about teaching, assessment, and research. Scantlebury et al. (2008) propose the introduction of coteaching|co-generative dialogues|co-respect|co-responsibility dialectic model into the teaching methods course and student teaching of preservice high school science teachers to support internship programmes. Because the model is specifically designed for the time the students are in teaching practice it does not stretch preparation to other aspects such as the development of the preservice teachers' subject matter knowledge, and standards in science teacher education. Suxman et al. (2010) also proposed a teacher preparation model that focuses on the development of a reform-minded science teacher. The model, the Collaboration for Leadership in Urban Science Teaching Evaluation and Research (CLUSTER) supports preservice teachers to appreciate the diversity of students and regard teaching and learning as socially constructed by providing the preservice teachers with opportunities for science teaching in work-related visits and other out-of-school settings. In the model, science majors at City College of New York (CCNY) spend up to ten hours a week at the New York Hall of Science (NYSCI) working as Explainers. According to Suxman et al. (2010), the Explainers' role involved multiple activities inclusive of interacting with hundreds of visitors at exhibits, leading demonstrations, and co-teaching in discovery laboratories and afterschool and summer science programs for K-8 students. However, while such models are useful lenses for gazing into some of the multiple dimensions of teacher preparation they leave out some components that are crucial to science teacher development.

This paper proposes a model that attempts to integrate most of the crucial dimensions for the preparation of reform-minded science teachers. The model is premised on the abundant opportunities for collaboration existing among colleges, school systems, and the private sphere that seeks to prepare and support a new generation of classroom teachers who work collectively to explore ideas and characterize science as a social endeavor based on representing ideas grounded in evidence (Brudbury, 2010; McGinnis et al., 2004). The model is thus designed around what McGinnis et al. (2004) termed salient reform-based recommendations, as follows: rigorous content and pedagogy courses that model inquiry-based, interdisciplinary approaches combined with regular opportunities for teacher intern reflection, the participation of departments of science education personnel, methods committed to modeling best teaching practices, and the development of field experiences in community schools with exemplary teachers trained to serve as mentors. Figure 1 below shows the five features of the model that if integrated effectively give rise to reform-minded science teachers.

Figure 1

Integrated model for science teacher preparation (Source: Own).



The model in Figure 1 above shows five aspects of an effective science teacher preparation program, namely: standards in science teaching, curriculum development, rigorous subject matter knowledge (content), research-based science teaching theory (methods course), and quality field experiences (practicum). The connecting green arrows show how the aspects are interactive and influence each other at every level.

Research-based Science Teaching Theory

Research-based science teaching theory (STT) that is constituted in methods courses is at the center of the model. The extent of effectiveness of preservice teachers' science content delivery during teaching practice depends on their ability to translate the acquired STT into practice. The relationship between the epistemic and cognitive aspects of science as represented in the disciplinary knowledge areas and the social and curriculum dimensions of science practices required during internship is interlaced in the science methods courses (Saribas & Ceyhan, 2015). A preservice teacher equipped with the nuances of subject matter knowledge but devoid of STT can become a loose cannon in front of the learners (Kvinge, 2019). Thus, it becomes crucially important to equip preservice teachers with the theory of teaching. This theory about effective approaches to science teaching is enhanced by an interplay with and amongst the other aspects- trends and standards in science teaching, curriculum implementation, and quality field experiences. A comprehensive methods course should therefore strive to inculcate the competencies enshrined in the other four areas to foster "…student scientific literacy and developing the ability to translate the theories of science education into classroom practice (O'Brien, 2015 p. 1). Such comprehensiveness may be covered through specific objectives such as those provided in the context of a science methods course of the Urban Institute for Teacher Education-University of Utah:

a. Articulate and refine personal understandings of science and science teaching
b. Develop a deeper understanding of the nature of science and specific science content
c. Demonstrate proficiency in identifying the essential features of inquiry-based science teaching and the variations within those features
d. Create developmentally appropriate lessons that demonstrate the effective application of important ideas and skills, including inquiry and process skills
e. Collaborate with other education professionals while examining issues related to teaching science to all students, including culturally relevant science learning and social justice issues related to science
f. Identify instructional approaches that facilitate learning by students from populations typically underrepresented in science, English Language Learners, and special education students (O'Brien, 2015 p. 2)

Accordingly, the objectives above are covered through teaching and assessment on aspects such as the definition of science, science process skills, the nature of science, the role of science in society, designing inquiry-based lesson plans, articles reflection, science fair projects, and development of science teaching papers (O'Brien, 2015). The integrated model for science teacher preparation contends that methods courses are not static but evolve through research input from science teachers. Rushton and Reiss (2019) say that research-active science teachers develop a multifaceted sense of professional identity and pedagogical content knowledge that enables them to mentor, coach, and interact positively with their students.

Rigorous Science Content/Disciplinary Knowledge

Science content relates to subject matter knowledge that pertains to teachers' academic areas of study. The academic study delineates the teachers' areas of specialization-biology, physics, chemistry, or other. That implies that science PSTs need to be grounded in their areas of specialization. The depth and breadth of a science teacher's content knowledge are enhanced by the rigor of approaches used in the acquisition of such knowledge (Lincoln, 2010). Lincoln (2010) asserts that higher-order thinking, alignment, building on prior knowledge, knowledge construction, and creativity are the six criteria that determine rigor in science content acquisition. Learning theories such as constructivism and approaches like scientific inquiry, engineering design, and problem-based learning set the tone for such rigor (Windschitl & Calabrese Barton, 2016).

At the intersection of rigorous science content and science teaching theory (see Figure 1) is pedagogical content knowledge (PCK). PCK is a concept that represents particular forms of pedagogical knowledge that are useful in teaching content in specific subjects such as the sciences. It is a representation first coined by Shulman (Shulman, 2015). In Shulman's terms representations and pedagogical and professional-experience repertoires "offer a way in which both the issues of particular science content (e.g., aspects students find difficult to learn, reasons why the content is important, ways of engaging students with the content, etc.), as well as specific ways of teaching that content (vignettes of particular teaching and learning episodes), can be captured and portrayed for others to offer insights into the nature of PCK" (Loughran, et al. (2008 p.1302). PCK is therefore conceived as the integration between content and pedagogy. It becomes a key that teachers use to unlock subject matter complexity (Shulman, 2015). The use of relevant and suitable pedagogical activities in teaching diverse topics becomes the domain of PCK (Juhji & Nuangchalerm, 2020). Science teaching orientations therefore underpin approaches to PCK. Citing Magnusson et al. (1999, Friedrichsen et al., 2011 p. 357) "…identify the following nine orientations to the science teaching process, academic rigor, didactic, conceptual change, activity-driven, discovery, project-based science, inquiry, and guided inquiry". Given this contention, PCK is arguably a component crucial for effective science teacher preparation programs.

Quality Field Practices and Purposeful Mentoring

Mentorship is a crucial aspect of science teacher preparation programs. To improve the PSTs' craftsperson, preparation programs should strive to impart the right practical teaching abilities. To achieve this, support in the form of time for practice in model schools and purposeful mentoring is needed (Carmi & Tamir, 2022). Purposeful mentoring implies deliberate support actions to raise the preservice teacher candidates through to their ‘zone of proximal development’. The literature cites educative mentoring as one example of purposeful mentoring. Educative mentoring is an approach coined by Feiman-Nemser (1998) where the target of mentoring is centred on co-thinking relationships between the novice teacher and the mentor. Bradbury (2010) posits that educative mentoring is founded on the idea that mentors and novices work together to cultivate dispositions of inquiry, develop alternative perspectives to teaching and learning, explore student thinking and understanding, make connections between topics within a discipline, develop appropriate instructional representations, meet the immediate needs and concerns of novices and their long- term orientation toward reform-based science teaching in ways that are supported by research. Thus preservice teacher candidates need to be attached to mentors with highly-developed science teaching skills coupled with abilities to co-teach, collaborate, apply PCK, and integrate STEM teaching strategies.

While various models for teacher preparation allow different durations for practice most scholars argue for an extended period (Binder et al., 2015). In Zimbabwe, for instance, the duration of a teaching practice stint depends on the program of study. In teacher education colleges, PSTs training under a two-year (Post ‘A’ Level) program practice teaching in two terms (6 months) while those on a year (Post 'O' Level) course are allowed a three-term (9 months) teaching practice stint. Ideally, these PSTs should be deployed to schools that have adequate resources (science laboratories, classrooms, financial and human resources) for science teaching. Garza & Harter (2016) contend that model schools that are adequately resourced, mentors who are sensitive to beginning teachers, modeling of STEM integrative approaches, and other orientations for science teaching constitute the backbone of successful internship in science teacher education. Expert mentors are therefore an important consideration for science PSTs. Research in the field of quality mentorship has shown that science PSTs mentored by specialists in their fields have more positive attitudes towards mentorship than their counterparts supervised by mentors from other fields of study (Mudavanhu & Zezekwa, 2009).

Trends/Standards in Science Teaching

The National Science Teachers Association (NSTA) (2003) identifies ten crucial standards, namely: content, the nature of science, inquiry, cross-cutting emerging issues, general skills of teaching, curriculum, science in the community, assessment, safety and welfare, and professional growth. Standard 2, the nature of science (NOS) has long been established as a critical component of science education that anchors science teachers in scientific literacy and enhances deeper conceptualization of the connection between science, technology, and society (STS). Pre-service student teachers need to go through details of NOS and its related concepts because according to an NSTA (2020: 4) document: "Practices and knowledge are entangled in the real world and classroom instruction, yet teachers of science need to know the difference between science practices and the characteristics of scientific knowledge to best lead students to a comprehensive understanding of nature of science". The totality of these standards therefore provide a framework of expectations that draw on a three-dimensional approach to learning science that integrates disciplinary core ideas of the life sciences, physical sciences, earth and space sciences, and engineering and technology; crosscutting themes that connect knowledge across these disciplines, and inquiry and engineering design practices that reflect how scientists and engineers engage in their work (Morrel et al., 2020). The NSTA standards are criticized for adopting a seemingly linear approach in disregarding the complexity of science teacher development (Enfield, 2007). As the NSTA (2020) aver there is no one universal way of the scientific approach that effectively captures the complexity of doing science. Several shared values and perspectives characterize a scientific approach to understanding nature. Among these is a demand for naturalistic explanations supported by empirical evidence that are, at least in principle, testable against the natural world. Other shared elements include observations, rational argument, inference, skepticism, peer review, and reproducibility of the work (NSTA, 2020 p. 5). This characterization of science calls for interactive rather than linear models.

A model proposed by Enfield (2007) utilizes the NSTA standards to present a cobweb of components that interact at every level. These components are inclusive of pedagogy, content, science curriculum, inquiry approaches, NOS, assessment, diverse social contexts for science teaching, professional practice, and learning environments. According to Enfield (2007), the interaction between and amongst the components is; driven by (e.g. reflection and research), embedded in, informed by, connected to, or relevant to. For instance, in inquiry models NOS, the context of science is embedded in the social context of science teaching and assessment drives pedagogy. In almost similar lines the integrated model for science teacher preparation presented in this paper identifies international trends in science teaching, teacher ethics, and professional standards, personal teaching philosophy, learning theories, expectations from examination boards, culture and indigenous knowledge systems (IKS) as guides for science teacher education that influence and is in turn influenced by expectations for content rigor, teaching and assessment approaches and the practice of science teaching. The knowledge that science educators should possess is bound to the framing of integrated knowledge systems. Integrated knowledge (iknowledge) systems are viewed as the total of knowledge systems a science teacher should possess to teach in the fourth industrial revolution (4IR). Jegstad et al. (2022 p. 1007) characterize the professional knowledge of science teaching as including "…content knowledge, communicative knowledge, knowledge about adult learning, feedback and motivation, research knowledge, and how to develop reflective competence within others". Such knowledge inclusive of integrated STEM/STEAM/STREAM education and other dimensions of science education is deemed critical for PSTs.

Also important to the creation of standards in science education is the creation of a personal teaching philosophy. A personal teaching philosophy is herein defined as a worldview about teaching that manifests and directs one's teaching behaviors. Beatty (2009 p.100) says:

> A statement of teaching philosophy is a narrative description of one's conception of teaching, including the rationale for one's teaching methods. It is seen as a place to voice holistic views of the teaching process, including one's thoughts about the definitions and interaction between learning and teaching, perceptions of the teacher's and student's role, and goals and values of education

In the integrated model for science teacher preparation possession of a teaching philosophy is therefore crucial for both science teacher educators and the preservice teachers because it shapes the teacher as a professional in science education. A personal teaching philosophy gives direction to the values and teaching actions for science learning that is reflective and inquiry-oriented. Erduran (2022 p.565) contends: "Philosophical reflections not only help us, as science educators, gain conceptual clarity on central issues (e.g. the definition of scientific methods) but also may inspire us to be creative and imaginative in designing innovative methodologies, analytical tools, and practical resources". Thus for the integrated model for science teacher preparation, a personal teaching philosophy is a valuable tool that sits at the intersection of the individual PST, subject matter knowledge, the philosophy of science, and pedagogy for science teaching. The science teachers' philosophy and the history, philosophy, and sociology of science represent the content and didactical strategies that can be used to unpack the scientific approaches, language, and epistemology of science and how these differ from other forms of knowledge (Martins, 2020).

Curriculum Implementation

Curriculum implementation is the act of putting into practice the course content of subject matter as contained in the syllabus documents and schemes of work. Chaudhary (2015) avers that implementation is how the teacher selects and mixes the various aspects of knowledge contained in a curriculum document or syllabus. Due to the centrality of the teacher's role in this process, preservice teachers need guidance in syllabus interpretation, drawing lesson plans from the schemes, the use and deployment of appropriate learning resources, and creating conducive settings for effective classroom interactive dynamics (Adegbola & Adeleke, 2023; Alvior, 2014). In the proposed model, curriculum implementation deserves special mention because it is the process through which emerging science teaching trends are brought to life through syllabus interpretation and actual teaching. The teacher educators and mentors are critical role models for orienting the preservice teacher in the process of curriculum implementation. As part of their role both the science teacher educators and school-based mentors need to model 'trialled and tested' teaching and learning strategies, assist preservice teachers with locating and using significant resources to teach science and assist with planning meaningful learning experiences to foster reform-minded science teaching (Petersen & Treagust, 2014). Research-based practices, reflective practice, creativity, aesthetical literacy, core practices in science teaching, and collaboration with stakeholders are components of curriculum implementation that can usher in reform-minded science teaching.

The impact of core practices in science education on curriculum enhancement is well documented in the literature. While many practices such as inquiry science and engineering design promote science learning Windschitl et al. (2012), propose four core practices. Firstly, is the practice they frame as "constructing the big idea". In the context of science education, big ideas are concepts or models that help learners understand, explain, and predict phenomena. Secondly, Windschitl et al. (2012) say teachers should endeavor to elicit student ideas to adapt instruction. This core practice is essential for novice teachers as it allows them to analyze students' ways of engaging with puzzling phenomena. The third core practice Windschitl et al. (2012) say science teacher candidates should help students make sense of material activity. It entails that learners present scientific arguments, explain themselves, construct theories, and justify claims. In the fourth core practice, teachers press students for evidence-based explanations. This core practice calls for the integration of theoretical and conceptual-based learning with laboratory work. In this paper laboratory work is construed as diverse bringing together virtual laboratories (virtual and augmented reality), physical traditional laboratory spaces, and hybrid laboratories. Accordingly, hybrid laboratories situate the traditional science laboratory, a computer laboratory, and engineering workshop equipment under one roof for STEM education and integrated approaches in the development of 21^{st}-century competencies (Mutseekwa, 2017). An endeavor to co-opt such core practices in one's teaching enhances the systematic development and management of the learners in virtual or physical learning spaces.

In a similar fashion, curriculum implementation that is premised on collaboration with stakeholders and involvement of the community is leveled as a critical requirement in the integrated model for improved science teacher preparation. It is clear from the extant literature that communities of practice or science learning communities created by expert teachers to share experiences and co-construct knowledge are part of the growing developments in science education. These learning communities are founded upon social and sociocultural learning theories, situated knowledge and learning theories, and the apprenticeship theory of legitimate peripheral participation, all representing some tenets of constructivism which views learning as a social process of making sense of phenomena based on individual prior experiences and active participation (Townley, 2020). Furthermore, Townley (2020) posits that communities of practice are premised on three basic assumptions (i) knowledge is a social process, (ii) knowledge is situated in a real-world context built on social interactions, and (iii) the development of meanings from these interactions and cultural practices of those concerned. Stroupe (2015 p. 487) frames the concept of science-as-practice in which students act as epistemic agents, "shaping the knowledge and practice of a science community…," working with their teachers and other stakeholders from the community in the public enterprise of science knowledge co-construction. Thus science-as-practice implies opportunities for the preservice science teachers to collaborate with peers, mentors, tutors, scientists, and community stakeholders to contribute to the socioeconomic well-being of society.

Laying Out the Agenda for an Integrated Model for Science Teacher Preparation

This paper has proposed an integrated approach to science teacher preparation. It has been argued that science teacher preparation is a complex phenomenon that requires the interaction of integrated components to enhance coherent preparation programs. The integrated approach advanced in this paper is drawn from the tenets of More for Teachers. The tenets- rigorous science content, research-based science teaching methods, and purposeful mentoring in quality field experiences all driven by a common vision of how adults learn and construct knowledge are presented in a linear structure as crucial for effective preparation models (Miller et al., 2013). While Miller's et al. (2013) model brings together important elements for coherent science teacher education programs its linear approach disregards the complexity of science teacher education, a phenomenon that recent literature (Kloser et al., 2019; Nordine et al., 2021; Sabramaniam, 2021; Vasquez, 2021) attests to. For instance, Vasquez (2021) argues for teacher preparation programs that take cognizance of this complexity and frame a "learn by doing" model that envisions the collaboration of pre-service student teachers with peers and experts in interactive, dialogic, and reflective scenarios (as explained under the sub-heading *Quality field practices and Purposeful mentoring* of Table 1). Similarly, the proposed integrated approach therefore premises itself on two pillars- integration and interaction to develop science teacher candidates with the requisite skills for secondary school science teaching.

In the integrated model for science teacher preparation, five components are brought together through the two pillars to produce the desired caliber of science teacher candidates. Inspired by the work of Darling-Hammond (2014) and drawing from Miller's et al. (2013) model, More for Teachers, the five components of the current model are trends/standards for science learning, rigorous science content, research-based science teaching methods, and purposeful mentoring in quality field experiences and curriculum implementation. The interaction of the five components in the integrated model proposed in this paper strikes similarities with a more recent model by Nordine et al. (2021). Nordine et al. (2021) suggest a 'Model for Science Teacher Education Programme Coherence (STEP-C)'. Like the current proposal which casts PCK as the knowledge the pre-service teacher acquires at the intersection of SMK and research-based teaching methods and later used during teaching practice, Nordine et al. (2021) anchored STEP-C on the Refined Consensus Model (RCM) of PCK that was developed by Hume and others in 2019. The RCM articulates three types collective, personal, and enacted. The construct collective PCK (cPCK) entails teachers' disciplinary knowledge as represented by topics, theories, principles, and concepts of specific science subjects while personal PCK (pPCK) represents a set of competencies for teaching, planning, delivery, evaluation, and reflection possessed through personal learning in science methods courses. Nordine et al. (2021) posit that pre-service teachers draw upon cPCK and pPCK to enact PCK (ePCK) as they plan and engage teaching. Thus, using the RCM frame STEP-C identifies critical programmatic elements that can be put together to design coherent programs for science teacher candidates with robust PCK.

In this paper, the context for science teacher development is set as an interaction between training agencies (Teachers' Colleges) and hosting schools for field placement. In contrast, STEP-C frames science teacher development in two circular contexts of university and schools with intersecting activities such as planning, reflection, and teaching centered around core ideas and practices for coherent science instruction (Nordine et al., 2021). The authors argue that intended coherent science curriculum development processes as represented through specific science subject regulations, exemplary curriculum plans, and standards in science education and research are organized for the pre-service teachers' development. However, similarly, the purposeful mentoring in quality field experiences component of the integrated model is enhanced through a dialogic partnership with schools the STEP-C model achieves enacted science curriculum through field experiences, mentors' observations, student teaching, and stakeholder engagement (Nordine et al., 2021). Despite the minor differences in contextual setting and conceptual focus of the models vital common and interacting components that are critical emerge, namely: unpacking standards, exemplary curriculum development processes, seminal research, core ideas and practices for science instruction, quality field experiences, stakeholder collaboration and a shared understanding on expectations for effective science teacher preparation programs (Mutseekwa, 2017; Nordine et al., 2021).

Another component that is regarded by the developed integrated model as bridging the theory-practice gap is field placement. In field placements pre-service teachers have the opportunity to apply science teaching theory (pedagogy) into practice, thus integrating cPCK and pPCK to enacted PCK (ePCK). Although some challenges relating to student teachers' low success in the implementation of teaching approaches such as restricted focus and disconnected field placements from university courses have been observed, recent research findings (Darling-Hammond, 2014; Kloser et al., 2019; Olufsen et al., 2021; Vasquez, 2021) have identified field placement as one of the key elements of coherent programs. Consistent with the line of arguments in the integrated model, the literature has highlighted several benefits of extended field experiences for coherent teacher preparation programs. Development of pre-service student teachers' teaching skills and professional abilities, development of PCK through matching of specialization areas with classroom practice, support from experienced mentors, and authentic contexts for teacher professional development are some of the benefits (Subramaniam, 2021; Olufsen, 2021; Vasquez, 2021). According to Cavanna et al. (2021), structural coherence is promoted when instructional approaches highlighted in methods courses are reinforced by collaborating with experienced mentors through an emphasis on core practices. Core practices refer to central aspects, ideas, and principles of pedagogy that are serialized into instructional packages (Kloser et al., 2019). Despite criticism that such recurring work is routine, predictable, and monotonous to learners, Kloser et al. (2019) say core practices provide a logical response to persistence challenges in teacher education. In the limitation of time and resources, such practices can be useful to steer the goals of learning if viewed in a broader sense as; prototypical but adaptable, adhering to underlying assumptions about teaching but allowing flexibility and reflective innovations on the interaction dynamics, and contextually designed to suit learners' backgrounds and needs (Carmi & Tamir, 2020; Kloser et al., 2021).

The integrated model has also argued for research-based science instruction. Regrettably, a dearth of research among teacher educators has been reported in the literature (Mutseekwa, 2017; Jakhelln et al., 2019; Jegstad et al., 2021). If teacher educators lack research experience and the zeal to cast themselves in that role they will experience difficulties identifying themselves with teacher education programs that are research-based (Jegstad et al., 2021). Despite the organisational and attitudinal barriers often cited as causing limited enthusiasm for research among teacher educators research competencies should be impressed among pre-service science teachers. Research is an inevitable approach to the scientific method hence the terms inquiry-oriented teaching, research-informed science, and research-based science instruction (Jakhelln et al., 2019). A general description of research-based teacher education that is also applied to science teacher preparation through action research is provided in the literature (Capobianco & Feldman, 2010; Pajchel et al., 2021). From the description, four types of research emerge. First is research-led, which aims at conceptualizing the research process and its interface with subject (Physics, Biology, Chemistry) content. Second is the notion of research-oriented, which seeks an understanding of the research process and findings of research. Third is research-based, where inquiry-based teaching and learning activities are emphasized. Last is research-tutored, which entails collaborative research done in communities of practice. Empirical evidence has confirmed the last two as more effective for use in science teacher preparation schemes (Jakhelln et al., 2019; Pajchel et al., 2021).

In Zimbabwe, pre-service science teachers are required to go through a Research Methods course and will engage in a research project as a requirement for their training. Not many of the Teacher Education institutions emphasize research-informed science teaching during field placement (Mutseekwa, 2017). The integrated model calls for research activities that go beyond just learning and doing research as a course component in college/university but engaging science teaching through action research. Pajchel et al. (2021) echo similar sentiments. The authors argue that to incorporate research in the student teachers' daily work and inculcate a disposition for research-based and research-tutored teaching an action-oriented approach is needed. According to Stenhouse (1975, as cited in Jakhelln et al. (2019), teachers should undertake systematic inquiry into their work and be able to identify, investigate, critique, reflect on, and change their practice. Pre-service science student teachers should be equipped to engage in inquiry-oriented practices to develop their capacity to investigate and find both effective and disorienting practices in their professional work (Capobianco & Feldman, 2010; Bendtsen et al., 2021; Pajchel et al., 2021; Jakhelln et al., 2021).

It is beyond the scope of this paper to expound on all that is needed for science teacher candidates with robust skills. However, the issues raised in the integrated model (see Figure 1) represent a package of dynamic competencies science teacher candidates should possess. For instance, for them to peak on requirements for science teaching they need professional science teaching competencies inclusive of knowledge of the current and emerging trends in science teaching, a good grounding on their specific SMK, robust PCK (e.g cPCK, pPCK, and ePCK) for science teaching, and science assessment knowledge. The model advances several aspects that are cited in other literature. Edelson et al. (2021) suggest openness and reception to learning (teacher learning), ability to adapt to diverse contexts for science teaching, integrative competencies, knowledge in the design of equitable instruction and enactment of some core practices, knowledge and skills in research and assessment for inquiry-oriented teaching and learning are some critical skills for science teacher candidates. Horning such skills in the prospective teachers requires self-aware candidates as defined in the artistic model for teacher preparation. This model frames the teachers' practice as a creative enterprise and experiential process driven partly by personal aesthetic values (Carmi & Tamir, 2022). According to Carmi and Tamir (2022), personal aesthetic values are represented in social, emotional, and rational sensitivities in the way a form is experienced. The experience and aesthetic dimensions attached to it are inseparable (Carmi & Tamir, 2022). In that light, Carmi and Tamir (2022) argue that teachers are creators of the learning process. They decide the best approaches to teach a particular topic, what materials to use, adaptations required for special needs education, which aspects of the concept to link with the learners' world views, the choice of vocabulary for use, and other aesthetic requirements that make the lesson delivery successful. Thus, preparing the preservice teachers for all these eventualities requires detailed and effective strategies that the Integrated model for science teacher preparation (see Figure 1) may provide.

Limitations

Conceptual ideas that are presented in the model arose from a study of contexts of science teacher development in Teachers' Colleges in Zimbabwe. While the Teachers' Colleges use the model already in theory, their approaches lack the rigour and detail suggested in the integrated model for science teacher preparation. However, implementing a wellspring of the suggested ideas in Zimbabwe may be met with several pushbacks. Firstly, the administration of teacher education is conducted under the Ministry of Higher and Tertiary Education, Innovation, Science and Technology Development while secondary schools where the preservice teachers practice teaching are under the jurisdiction of the Ministry of Primary and Secondary Education. Policy harmonization for teacher development may present challenges under such a setup. Secondly, the low morale due to poor remuneration and a lack of motivation for the mentors working in the practicing schools may militate against effective and purposeful mentoring. Finally, science teacher development is also done in universities in which contexts were not discussed in detail. Therefore, transferring the application of the proposed model should be done cautiously.

Conclusion and Recommendations

In this conceptual paper, the importance of following particular approaches to science teacher preparation has been highlighted. Although crafting such models can be a challenging process, several aspects of existing models can be put together. The paper has drawn from a theoretical framework (MORE for Teachers) and a conceptual frame that aims to develop science teacher candidates with the right skills. The integrated approach espoused above is also aligned with Carmi and Tamir's (2022) teacher preparation model that embraces theoretical knowledge, practical know-how, creativity, and aesthetical literacy. The five components of the current model that are suggested to guarantee an effective science teacher preparation program are; standards in science teaching, curriculum implementation, rigorous content, research-based science methods course, and quality field experiences. The integrated model for science teacher preparation has therefore been presented as a valuable tool that is useful to teacher educators, standards, and quality control boards (such as ZIMCHE and Centre for Teacher Education and

Materials Development of the UZ) in developing science teacher education programs that integrate definitive aspects of preparation. In the context of Zimbabwe, the practical implications for implementation of the proposed model mean that the Centre for Teacher Education and Materials Development of the UZ may be required to (i) revisit the design and review of science education syllabi in teachers' colleges with the view to ascertain aspects important to science teacher education that colleges are currently not emphasizing, (ii) conduct professional development workshops for science teacher educators and mentors on the design and development of coherent and integrative preparation programs, and formulation of collaborative communities of practice (iii) apprise the ZIMCHE on how commonalities between science teacher development in teacher education colleges and universities can be achieved (iv) establish a statutory board that formulates policies on the harmonization and implementation of science education in junior and secondary schools, teacher education and university colleges.

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Please Cite: Mutseekwa, C. (2024). Towards an Integrated Model for Orienting Preservice Science Teachers for 21st-Century Teaching. *International Educational Review*, *3*(1), 1-19. DOI: https://doi.org/10.58693/ier.311

Conflict of Interest: No conflict of interest

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Data Availability Statement: The paper is a review article.

Ethics Statement: Not Applicable

Author Contributions: Not Applicable

Received: March 16, 2024 ▪ Accepted: July 09, 2024