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Vygotsky's Zone of Proximal Development of Teaching and Learning in STEM Education

Latifa Rahman
School of Education, St. John's University, New York

Abstract
The purpose of this article is to highlight essential elements of Vygotsky's (1978) ideas on the topic, including the Zone of Proximal Development (ZPD) in teaching and learning in Science, Technology, Engineering, and Mathematics (STEM) education. To investigate the zone of proximal development applications to teacher professional development for teaching and learning presents examples of recent research to the literature review in research and practice with the concept of Vygotsky on learning and development, collaboration in zone the of proximal development, zone of proximal development, and scaffolding teaching and learning, inquiry-based questions as a form of scaffolding and teaching and learning in STEM education. Using Vygotsky's Zone of proximal development (ZPD) in teaching and learning scientific conceptions provides an attractive metaphor for designing instruction and examining knowledge into practice, which has long been a subject of intense interest in STEM education.
***Keywords*: Zone of proximal development (ZPD), collaboration learning and teaching, STEM education, scaffolding teaching and learning.**

INTRODUCTION

Vygotsky's psychology (Vygotsky, 1978) states that the human mind is constructed through a subject's interactions with the world and is an attribute of the relationships between subject and object. Vygotsky's complete developmental continuum comprises four stages: phylogenetic (transformation from ape to human), sociohistorical (primitive to modern), ontogenetic (child to adult), and micro-genetic (less to more capable individual) (Berducci, 2004). Vygotsky claims that at the earliest stages of the development of thought and speech in the human child, an analogy can be drawn between human children and chimpanzees in that they have natural biological abilities that enable them to react to stimuli (Vygotsky, 1986) The thought and speech are biological, based on an innate, natural form of behavior (Vygotsky, 1986); they are 'intellectual' and 'prelinguistic' (Vygotsky, 1986). In the early stages of consideration, Vygotsky moved onto the development continuum and participated in external speech (Berducci, 2004). Vygotsky has used his observations of children learning to infer the existence of the supposed inner modes of Private speech, inner speech, thought, and motivation and the attempted resolution of this problem name that the inner modes are transformations of the outer moods and can thus be seen directly, merely assumes the continuum that it is meant to justify (Newman, 2018).

Vygotsky's zone of proximal (ZPD arises from a set of observations that described as having found that the mental age of two children was, we gave each of them more complex problems than he could manage on his own and provided some slight assistance: the first step in a solution, a leading question, or some other form of help. It discovered that one child could, in cooperation, solve problems designed for twelve-year-olds while the other could not go beyond problems intended for nine-year-olds. The discrepancy between a child's actual mental age and the level he reaches in solving problems with assistance indicates the zone of his proximal development (Vygotsky, 1986)

For teaching and learning, it means that both the teacher and the student are seen as active agents in children's learning. Teacher intervention in children's learning is necessary, but the quality of teacher-learner interaction is seen as crucial in that learning (Tharp & Gallimore, 1988). This method is associated with social Constructivism, which emphasizes the role of social interaction in development and learning. According to Kuusisaari, 'The Vygotsky approach is the study's theoretical basis, emphasizing the importance of coloration in learning (Kuusisaari, 2014). Vygotsky's (1978) concept of the zone of proximal development (ZPD) offers a theoretical approach to the research of teacher development in the study and that 'the board theoretical framework of the research in the ZPD as a tool for understanding the process of collaborative knowledge creation' (Kuusisaari, 2014).

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Vygotsky's social theory of Constructivism developed the STEM module, which provides a learning platform for students to connect with peers while completing tasks and implementing practical problem-solving skills in their respective Proximal Development Zones. According to the Social Theory of Constructivism, students build concepts through interaction until a new concept emerges, resulting in Proximal Development Zones (ZPD). The Proximal Development Zone is the distance between a child's ability to accomplish a task under adult guidance and the child's ability to solve a problem independently (Vygotsky, 1979).

LITERATURE REVIEW

Vygotsky on learning and development

Vygotsky is best known for his general law of cultural development, which states that every function in the cultural development of the child appears on the stage twice, first on the social plane and then on the psychological plane, first between people as an inter-mental category and then within the child as an intramental category. It pertains equally to voluntary attention, logical memory, the formation of concepts, and the development of will (Vygotsky, 1997).

Vygotsky's primary objective was to identify specifically human aspects of behavior and cognition via genetic analysis mythology (Kozulin, 1990). He focused on several different of development: human evolution (phylogenesis), development of human cultures (sociocultural history), individual development (ontogenesis), and development that occurs during a learning session or activity or very rapid change in one psychological function (micro genesis) (Wertsch, 1991).

Adopting Vygotsky's ideas about the development of scientific concepts is not just a shift in emphasis, but a collaborative effort that involves scholars, teachers, and curriculum developers. While any change in classroom practice will be a shift in emphasis rather than a radical change, the ways that scholars, teachers, and curriculum developers think and talk about instruction eventually finds its way into the classroom. Science lessons, under this new paradigm, aim for students to make sense of their environment through exploration, experimentation, and discussion. There is a renewed emphasis on the importance of using manipulable objects (hands-on science) and the teacher's role in creating a supportive climate where children can work. A Vygotskian perspective provides a different focus and may yield insights that have yet to be available. It shifts the focus from the child as a solitary thinker to the child in a social context, where every day concepts are integrated into a system of relational concepts through interaction, negotiation, and sharing.

THE ZONE OF PROXIMAL DEVELOPMENT

The best-known concept of Vygotskian theory is the zone of proximal or potential development (ZPD). In Mind in Society: The Development of Higher Psychological Process, Vygotsky defined the Zone of Proximal Development as "the distance between the actual development level as determined by independent problem solving and the level of potential development as determined through problem-solving under adult guidance or in collaboration with more capable peers." (Cernusca et al., 2018)

Initially, it was elaborated for psychological testing at school. Vygotsky stated that testing should be based on the current level of a child's achievement and potential development. The term proximal indicates that the assistance provided goes slightly beyond the learner's current competence, complementing and building on their existing abilities (Aila et al., 2015). Vygotsky recognized that the distance between doing something independently and with the help of another indicated stage of development sometimes coincides in some people. In this way, Vygotsky regarded an instructor's "teaching of a student not just as a source of information to be assimilated but as a lever with which the student thought, with its structural characteristics, is shifted from level to level." (Venenikina, 2004, p.44).

The effectiveness of the zone of proximal development rests on the quality of verbal interactions that take place between educators. This educational discourse, according to Manning and Payne, "shapes teachers thinking as knowing is a collaborative, socially constructed process. However, Vygotsky theories have become increasingly supported, and the practical applications of these theories in practice. Vygotsky framework to examine changes in STEM teachers' knowledge. By constructing an environment to foster development within the zone of proximal development for STEM teachers to promote conceptual growth.

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COLLABORATION IN ZONE OF PROXIMAL DEVELOPMENT

The zone of proximal development is assessed through collaboration with learners because it provides an opportunity for imitation, identifying maturing psychological functions that are inadequate for independent performance. The primary focus of collaborative interventions is finding evidence for maturing psychological functions, assuming that the learner can only take advantage of these interventions because the maturing function supports an ability to understand the significance of the support being offered (Chaiklin, 2003).

Vygotsky used collaboration procedures and interpretations as diagnostics in instructional experiments to identify learners who had larger and smaller zones of proximal development. In his 1934 study, Vygotsky described a set of experiments in which learners were tested and identified to have a high or low IQ and a large or small zone. The larger zone with learners of the zone of proximal development had comparable gave a better indication for understanding future intellectual development than a measure of independent performance because it focuses on maturing functions (Valsiner, 2001).

In a collaborative learning environment, students work together towards a common goal and assist each other in learning complex STEM concepts through peer-to-peer interaction. This process deepens everyone's understanding of STEM and fosters a sense of trust and responsibility. The collaborative dialogue in the quest for knowledge not only internalizes the information provided but also empowers students to use that information to guide their actions. STEM education, a cornerstone of the 21st century, relies heavily on collaborative learning to pool students' knowledge and share information, leading to discoveries and nurturing the Scientists of tomorrow (Lauren, 2023).

ZONE OF PROXIMAL DEVELOPMENT AND SCAFFOLDING

The interpretations and understanding of scaffolding as a direct application and operationalization of Vygotsky's concept of teaching in the zone of proximal development (Wells, 1999), to the view that the notion of scaffolding partially reflects the richness of Vygotsky's zone of proximal development (Daniels, 2001). In addition, the limitations of the metaphor of scaffolding in interpreting the zone of proximal development have been revealed (Stone, 1998). The primary goal of scaffolding in teaching is to provide a view of the zone of proximal development characteristics of the transfer of responsibility for the task to the student (Mercer & Fisher, 1993). They emphasize the collaboration between the teacher and the learners in constructing knowledge and skills. Lave and Wenger (1991) mention that the zone of proximal development, which emphasizes teacher-leaner collaboration and negotiation as a bilateral process, contrasts scaffolding that captures teaching performance as a one-way communication process. In scaffolding, the scaffolder constructs it alone and presents it to the novice (Daniels, 2002).

The quality of teacher-learner interaction is seen as crucial when scaffolding learners' learning (Bodrova & Leong, 1996). Researchers are highlighting the scaffolding metaphor's limitations, stating that several educational and development studies question its theoretical and practical value. However, the metaphor should be supported (Stone, 1998).

On the broader group, there was evidence that some students were prepared to make time to support their peers, and this change could be interpreted as an example of critical action (Barnett, 1997). These formal and informal conversations helped students towards what one described as "thinking like a researcher." Curriculum components that provided conversational space included fieldwork, research training exercises, and group research projects. These supported changing dispositions as students matured. "Attitudes" have been seen as a form of self-scaffolding (Bickhard, 2005, p. 45) when it leads the student to use self-evaluation or a skill, such as breaking a task down into more manageable components to extend their zone of proximal development.

The zone of proximal development is the difference between what a learner can do without help and what a learner can do with help. Scaffolding is a process that supports students as they learn to perform a task independently. Vygotsky defines it as the distance between the actual development level determined through problem-solving under adult guidance or in collaboration with more capable peers.

The discussion about using ZPD in teaching and learning STEM in mathematics indicates the importance of providing physical and psychological resources to teachers and learners. Discussing the availability of physical and psychological resources might not be enough. Another aspect is the availability of human resources, that is, teachers of high caliber. Atebe (2011) states that no curriculum prescription of the body of knowledge students are expected to learn in mathematics can be said to be complete without specifying how best the students might be apprenticed into acquiring that knowledge.

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INQUIRY-BASED QUESTIONS AS A FORM OF SCAFFOLDING

Questioning is vital for teaching and learning. It is an essential part of the inquiry process, allowing teachers to assess their student's knowledge and assist them as they progress through activities. Questioning can encourage students to think, analyze, and offer further evidence of their ideas. Questions have also been shown to be a valuable scaffold for helping students solve ill-structured problems. GE and Land (2003) used written question prompts with students solving an ill-structured task on information science and technology. Examples of questions included "What are the parts of the problem?" and "How would I justify this specific system design?" They found that students who were given question prompts were better able to organize and plan their solutions, construct arguments and justifications, and evaluate their products.

Inquiry-based questions are designed to be asked within a dialogue with students. Inquiry questioning involves the teacher responding to students' statements or actions with questions for students to follow up on (Mortimer & Scott, 2003). This pattern of questioning and response promotes students' understanding and can assist the teacher in exploring students' ideas (Mortimer & Scott, 2003). Students' responses are used as a platform for advancing inquiry, and the questioning can help bridge a gap in student understanding (Chin, 2007).

Despite its challenges, the implementation of inquiry-based instruction is not just a method, but a gateway to inspiring students and addressing critical issues in STEM. This approach transforms STEM from a set of disciplines into a multidisciplinary construct that can tackle pressing, real-world issues. The success of this instruction hinges on the teacher's readiness to facilitate inquiry (NRC, 2006). While the challenges of implementing inquiry are well-documented (Roehrig & Luft, 2004), the potential for inspiration and addressing critical issues is equally significant.

TEACHING AND LEARNING IN STEM EDUCATION: VYGOTSKY ZONE OF PROXIMAL DEVELOPMENT

The teacher's zone of proximal development is through as a learning space between his present level of teaching knowledge consisting of content (theoretical) and pedagogical knowledge and skills his test (potential) level of knowledge to be attained with the support of others (Blanton et al., 2005). The definition provides us with the possibility not to restrict ourselves to regard educators as the only source of scaffolding and think of some other sources like the teachers' colleges, researchers in the field, student achievement data, narratives, observation, action research, pre-service, and in-service course room as another resource of scaffolding that can change the teacher zone of proximal development (Karim et al., 2010).

To enhance ZPD progression, teachers must continually define goals throughout their teaching and learning in life. Their prior experiences of passive learning and blind dependence on other teachers usually hinder the teachers from theorizing their pedagogical knowledge and from moving up through their ZPD (Karim et al., 2010). Teachers need to make changes in their careers, go through professionalism, and determine their tasks in the classroom and how to develop, negotiate, use, and control knowledge (Helsby & McCulloch, 1996).

The idea that teachers benefit from their collaborative colleagues' and coaches' encouragement and support is widely accepted. The increased collaboration with supportive colleagues or literacy coaches can provide a much-needed boost to teachers when they face challenges that dent their self-confidence, such as a lack of experience and self-efficacy (Karim et al., 2010). Nielsen et al. (2007) suggest that one effective way to grow professionally is to attend classes conducted by exemplary teachers and coaches and observe their teaching methods, strategies, and techniques.

Research shows that Vygotsky's Zone of proximal development allows active learners to become more active, take initiative, plan, and produce results. The learning results are "personal and self-constructed preparing form and leading to future experiences" (Marlow & McLain, 2011, p.5), which makes teachers lead the classroom differently after attending the zone of proximal development. According to Bruke (2013), the experimental approach allows participants to improve their teaching practices through self-directed growth and hands-on experiences to create spaces to explore and empower teachers to stimulate students' STEM learning experiences through hands-on pedagogy and change students' attitudes towards STEM.

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DISCUSSION AND CONCLUSIONS

Throughout the article, Vygotsky endeavored to provide insights into the Zone of Proximal Development concept as a review and alternative to static, individual testing, namely IQ testing. The assessment of cognitive functioning was developed using Vygotsky's term (1978); mental procedures must be developed through cooperative, not independent or isolated activities. Vygotsky's characterization of the Zone of Proximal Development is that considering an individual's development is not enough to determine their neuropsychological ability; we must also uncover their inter-psychological capacity.

As this paper discusses, a literal interpretation of the scaffolding metaphor could lead to a limited view of learner-teacher interaction, portraying the learner as a passive recipient of the teacher's guidance. However, a deeper grasp of the scaffolding metaphor's theoretical basis will empower educators to use it more creatively and informally.

The formation of a new type of student thinking occurs in a fundamentally diverse way from how it is described in the classical version of the theory of learning activity in the process of forming scientific concepts. According to the initial position by Vygotsky's, it is not scientific concepts that are formed, but their synthesis with initial concepts as a fundamentally different, two-sided process not only from top to bottom but also bottom to top by comprehending and generalizing initial concepts along with their rise and connection with scientific ideas.

Vygotsky established at least two significant, interrelated instructional implications from his concept of the zone. One is that effective instruction must be prospective and aimed at a learner's proximal level of development, or "the upper threshold of instruction." Vygotsky suggested teachers must orient their work "not on yesterday's development in the child but on tomorrow's. The second important is that the learner will later perform independently with collaboration or assistance. Vygotsky suggests that creating a zone of proximal development helps to define the learner's primary and future learning. The zone of proximal development is the characteristics of the collaborations that create the proximal group and define the parameters for the learner's future independent performance (Moll, 1990).

As discussed in this paper, a literal interpretation of the scaffolding metaphor might lead to a narrow view of learner-teacher interaction, with the learner as a passive recipient of the teacher's direct instruction. However, a deeper understanding of the scaffolding metaphor's theoretical underpinning is crucial, as it can promote educators' creative and informed use of it.

Lantolf (2004) states that Vygotsky's characterization of the ZPD clearly shows that determining a person's inter-psychological knowledge is insufficient; it must uncover the inner psychological capacity. On the other hand, observing a person's history (actual level of development) presents part of the picture; the whole picture emerges when considering the person's future.

STEM teachers should be encouraged to participate in local and national conferences and share teaching strategies and techniques with their colleagues. That might raise their enthusiasm. Academic leaders need to devise appropriate means to restore the value of teaching so that teachers can maximize their potential and effectively comprehend the teaching-learning techniques of STEM education. This can also support the pedagogical content knowledge of STEM education, which can introduce different methods of teaching STEM.

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