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COMPARATIVE PERSPECTIVES ON CHEMISTRY TEACHING AND LEARNING IN HIGHER EDUCATION

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Science learning in higher education has been examined in light of the cognitivist and constructivist theories of learning and ways in which these theories can inform teaching practices. Science teaching practices have been studied from developmental and pedagogical content knowledge perspectives. This paper provides a review of seminal and recent literature on research advances in chemistry education, and the application of constructivist learning theories to teaching and learning.

Keywords: Chemistry; Higher education; Constructivism

INTRODUCTION

The understanding of the sciences often involves learning barriers that include difficulty in the comprehension of abstract concepts. Teaching and learning of scientific concepts are reported as very challenging for both teachers and students due to the misconceptions formed by students, which could be due to ineffective teaching practices, confusing statements provided in textbooks, or gaps in their prior knowledge base (Johnstone, 1991). Students often find it difficult to think critically and apply knowledge towards problem solving (Gabel, 1999). There have been numerous studies in the past that have focused on how the learning of science occurs and how this

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knowledge about learning can be effectively utilized to facilitate instruction (Cooper & Sandi-Urena, 2009; Johnstone, 1997; Osborne, 1996; Rickey & Stacy, 2000).

MISCONCEPTIONS IN SCIENCE LEARNING

Chemistry learning often involves representation of concepts at three levels: macro (physical), sub-micro (particulate) and symbolic (including the the use of mathematical symbols, formulae, and equations) (Johnstone, 1991). Building on Bruner's (1966) three-stage model of knowledge representation, Lin (2015) suggested that teachers can support learners through designing phased activities: (1) enactive activities (where learners benefit from engaging in physical tasks), (2) iconic activities (where learners benefit from engaging with visual representations), and (3) symbolic activities (where learners are ready to work with abstract terms and symbol systems). Mahaffy (2004) added the *human influence* component to the above three-component representation, modifying it to a four-component tetrahedral representation. He asserted that teaching and learning of chemistry depends upon diverse influences of society and the living environment that surrounds us. The inadvertent switching of concepts from one level to the other by teachers makes it difficult for students to connect the three levels in order to completely understand the concept. When chemistry teachers do not understand the stages/levels of students' understandings that they need to support, students' understandings of concepts can be limited to the surface features of the macroscopic representation, such as color and appearance of a chemical substance (Weerawardhana, Ferry, & Brown, 2006). Students often also find chemistry principles and chemicals as alien to their everyday lives (Gabel, 1999). Another barrier to learning is the use of language during instruction, which if not used carefully, can mislead the students (Gabel, 1999). If the structure of curriculum in textbooks is inappropriately sequenced to support student learning, curriculum can become a roadblock for newcomer students (Gabel, 1999). Sometimes, curriculum overload can be an extrinsic motivator for students, which can cause them to follow surface approach to learning. While students who achieve surface learning can do well in exams, there is little evidence of meaningful conceptual learning (Pratt, 1998).

In order to build a comprehensive understanding of student learning barriers and to come up with effective strategies in dealing with them, viewpoints of both science education researchers and learning theorists need to be considered. The following sections provide review of research on constructivist theories of learning and teaching practices based on the developmental perspective on teaching. An account on research from science education has been provided along with these theories and perspectives of theorists and science education researchers have been correlated in the present context of addressing student learning barriers.

PRIOR KNOWLEDGE: CONSTRUCTIVIST THEORIES OF LEARNING

Cognitivist and constructivist theorists argue that teaching and learning are not synonymous (Ormrod, 1995). Both cognitivist and constructivist learning theories emphasize the role of prior knowledge and experiences as fundamental structures on which further knowledge is built (von Glasersfeld, 1984). Constructivist theories of learning focus more on social processes involved in constructing new knowledge through interdependent interactions among learners and teachers that include engagements with learning resources and physical artifacts within designed social learning activities (Parchoma, 2015).

The constructivist approach focuses on "reflection on experience" (Fenwick, 2003, p. 22) and it is only when learners are able to critically reflect upon their prior learning experiences and connect their new knowledge to those experiences, can they construct new understandings. Constructivists view learning as an active process where learners construct knowledge, rather than passively absorbing it (Fox, 2001). Knowledge is also considered to be a personal and idiosyncratic process

(Fox, 2001). Teachers can work as facilitators of reflection and have the students be involved in learning tasks that provide opportunities for critical reflection (Fenwick, 2003).

As learners confront new ideas, they try to fit it into their existing schema and if there is a mismatch, they try to either modify an existing understanding or create a new one. Sheckley and Bell (2006) suggested that the process of reflection involves reinterpreting the past experiences in light of new experiences. When new experiences do not fit the patterns that already exist, brain makes meaning of these experiences by making new connections from an alternate perspective. Mezirow (1990) describes this experience as a *disorienting dilemma*.

The constructivist theories elucidate why misconceptions formed by science students are resistant to instruction (Bodner, 1986). When new knowledge presented to the students doesn't fit with their prior experiences, they try to replace a misconception by constructing a new concept that explains their experiences in a better way. Unless the misconceptions are dealt by constructing new concepts, no amount of instruction can help students change their conceptualizations.

The social constructivist models consider that learners construct new knowledge by reflecting and building upon their previous understanding through social interaction. Social constructivism has established a strong foundation for *mathematics and science education* (Atwater, 1996) and offers practical strategies for addressing student misconceptions (Osborne, 1996). Participating in group discussion plays an important role in increasing student capacity to test ideas, analyze others' ideas and build a deeper understanding of their learning (Nystrand, 1996; Wieman, 2007). Social interaction also increases self-regulation, motivation, collaborative skills and the problem-solving abilities (Matsumura, Slater, & Crosson, 2008).

According to Novak (2010), multicultural science education involves five elements in the education process: science learner, science teacher, science curriculum, context or social milieu of the science classroom and evaluation of these elements. Keeping these elements in mind, it is apparent that the process of learning is idiosyncratic for each individual, and therefore, there needs to be a negotiation of meaning between the teacher and students and also amongst students for meaningful learning to occur.

The social constructivist theories fit well with the teaching and learning of science and learning in a social context is an important element of meaningful scientific learning. Meaningful learning involves both implicit and explicit learning processes (Vygotsky, 1986). The implicit learning process involves embodiment of knowledge after making interpretations from the social environment without mindful reflection. The explicit learning process, on the other hand, includes interaction with others through dialogue, brainstorming, and discussion, and through these processes, the activation of prior knowledge takes place.

SCIENCE INSTRUCTION: THE DEVELOPMENTAL PERSPECTIVE

The developmental perspective is the "emergent dominant perspective" (Pratt, 1998, p. 45) in North American education system today, particularly in the area of *science education*. The developmental perspective fits well with the constructivist learning approaches (Candy, 1991). Both perspectives value prior knowledge as a foundation on which new knowledge is built and argue that it is necessary to activate learners' prior knowledge in order to support them in constructing new knowledge. Touching upon the concept of Vygotsky's (1978) zone of proximal development (ZPD), Pratt (1998) suggested that teachers should start their instruction from the students' ZPD, so that instruction is neither too simple nor too challenging for the students. ZPD is the activity zone in which learners cannot demonstrate their knowledge by means of their own capacity but can only do that with support. Vygotsky (1986) emphasized that student's learning is limited by their proficiency in what they already know and development of knowledge beyond this zone requires interpersonal interaction, scaffolding and mindful delivering of information by the teacher. Effective instruction demands that no assumptions should be made about learners' prior understanding; rather the learners should be given an opportunity to express what they already know.

Within the developmental perspective, teachers act as *mentors*, who challenge students to find answers to their questions (Pratt, 1998). Students share control with the mentor, collaboratively negotiating the effectiveness of the teaching practice and their experiences. The intention of the mentors is to provide the learners with more questions than answers. It is assumed that teaching from this perspective takes place in a safe environment where the learners are encouraged to express their thoughts freely and the teachers refrain from criticizing and judging the students. If, on the contrary, students are confronted frequently with their shortfalls, the great ideas that they come up with will die out even before being born. In such a scenario where the students' self-esteem is challenged, there is indeed no learning as the focus shifts from gaining knowledge to preserving one's self-esteem (Whitman, 1990).

Pedagogical content knowledge

Other than mastering the content and gaining knowledge on effective teaching strategies for dealing with student misconceptions, teachers need to attain proficiency in the pedagogical content knowledge (PCK), which is defined as the knowledge about the teaching and learning of a particular subject that takes into account the specific intrinsic learning demands of the discipline (Shulman, 1986). Likewise, Pratt (1998) defined PCK as the "bridging knowledge" (p. 134). Pratt highlighted that teachers often try to gain expertise in the subject matter (content expertise) and the general principles of teaching (process expertise); however bridging knowledge involves transforming the content for teaching purposes. PCK includes both content knowledge (understanding of the subject matter) and pedagogical knowledge (understanding of the teaching and learning processes independent of the subject matter). Bucat (2004) commented that the accumulated PCK of teachers "grows with experience, peaks at retirement and then disappears" (p. 225) without contributing much to the common shared understanding of the teaching profession, which he calls *professional amnesia*. This situation thus calls for the application of PCK in the classroom and the need for research studies in the area of PCK that can illuminate content-specific knowledge and teaching strategies amongst the scientific community (Bucat, 2004).

CONCLUSIONS

Peer reviewed literature on constructivist learning theory and science education research shows compelling evidence suggesting that prior knowledge is paramount in the learning process. Social interaction is an important dimension of science learning and thus teaching and learning of the sciences can be comprehended and evaluated from the social constructivist perspective with a high degree of accordance.

Extensive studies on science education research draw attention to learning barriers that chemistry students confront in the classroom environment and necessitate informed instruction that is integrative of knowledge that encompasses perspectives of both learning theorists and science education researchers. Chemistry instructors who are able to recognize initial student misconceptions can purposefully design learning activities that incorporate contextualized technological and physical resources, demonstrations, and phased enactive, iconic, and symbolic learning scaffolds that meet their learners' needs. In order to systematically undertake this complex approach to teaching, instructors need to be able to build bridges between deep understanding of chemistry constructs (disciplinary expertise) and praxiological (theory into practice/process expertise) to support chemistry learners in overcoming misconceptions.

REFERENCES

Atwater, M. M. (1996). Social constructivism: Infusion into the multicultural science education research agenda. *Journal of Research in Science Teaching*, *33*(8), 821-837.

Bodner, G. M. (1986). Constructivism: A theory of knowledge. *Journal of Chemical Education*, *63*, 873−878.

Bruner, J. (1966). *Toward a theory of instruction*. Cambridge, MA: Harvard University Press.

Bucat, C. (2004). Pedagogical content knowledge as a way forward: Applied research in chemistry education. *Chemistry Education: Research and Practice*, *5*(3), 215-228.

Candy, P. C. (1991). *Self-direction for lifelong learning* (1st ed.). San Francisco, CA: Jossey-Bass.

Cooper, M. M., & Sandi-Urena, S. (2009). Design and validation of an instrument to assess metacognitive skillfulness in chemistry problem solving. *Journal of Chemical Education*, *86*(2), 240−245.

Fenwick, T. (2003). *Learning through experience: Troubling orthodoxies and intersecting questions*. Malabar, FL: Krieger Publishing.

Fox, R. (2001). Constructivism examined. *Oxford Review of Education*, *27*(1), 23-35.

Gabel, D. (1999). Improving teaching and learning through chemistry education research: A look to the future. *Journal of Chemical Education*, *76*(4), 548-554.

Johnstone, A. H. (1991).Why is science difficult to learn? Things are seldom what they seem. *Journal of Computer Assisted Learning*, *7*(2), 75-83.

Johnstone, A. H. (1997). Chemistry teaching-science or alchemy? 1996 Brasted Lecture. *Journal of Chemistry Education, 74*(3), 262.

Lin, L. (2015). Constructivist theory. In J. M. Spector (Ed.). *Encyclopedia of educational technology* (pp. 144-146). Thousand Oaks, CA: Sage.

Mahaffy, P. (2004). The future shape of chemistry education. *Chemistry Education: Research and Practice*, *5*(3), 229-245.

Matsumura, L. C., Slater, S. C., & Crosson, A. (2008). Classroom climate, rigorous instruction and curriculum, and students' interactions in urban middle schools. *The Elementary School Journal*, *108*(4), 294-312.

Mezirow, J. (1990). *Transformative dimensions of adult learning*. San Francisco, CA: Jossey-Bass.

Novak, J.D. (2010). *Learning, creating, and using knowledge: Concept maps as facilitative tools in schools and corporations* (2nd ed.). New York, NY: Routledge, Taylor-Francis.

Nystrand, M. (1996). *Opening dialogue: Understanding the dynamics of language and learning in the English classroom*. New York, NY: Teachers College Press.

Ormrod, J. E. (1995). *Human learning* (2nd ed.). Englewood Cliffs, NJ: Merrill.

Osborne, J. F. (1996). Beyond constructivism. *Science Education*, *80*(1), 53-82.

Parchoma, G. (2015). Distributed cognition in computer-supported collaborative learning. In J. M. Spector (Ed.). *Encyclopedia of educational technology* (pp. 233-237). Thousand Oaks, CA: Sage.

Pratt, D. D. (1998). *Five perspectives on teaching in adult and higher education*. Malabar, FL: Krieger Publishing Company.

Rickey, D., & Stacy, A. M. (2000). The role of metacognition in learning chemistry. *Journal of Chemical Education*, *77*(7), 915–920.

Sheckley, B., & Bell, S. (2006). Experience, consciousness and learning: Implications for instruction. In S. Johnson, & K. Taylor (Eds.), *The neuroscience of adult learning: New directions for adult and continuing education, number 110* (pp. 43-52). San Francisco, CA: Jossey-Bass.

Shulman, L. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4-14.

von Glasersfeld, E. (1984). An introduction to radical constructivism. In P. Watzlawick (Ed.), *The invented reality: How do we know what we believe we know?* (pp. 17-40). New York, NY: Norton.

Vygotsky, L. S. (1986). *Thought and language* (Rev. ed.). Cambridge, MA: MIT Press.

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Cambridge, MA: Harvard University Press.

Weerawardhana, A., Ferry, B., & Brown, C. (2006). Use of visualisation software to support understanding of chemical equilibrium: The importance of appropriate teaching strategies. *Proceedings of the 23rd annual ascilite conference: Who's learning? Whose technology? The University of Sydney*, 853-861.

Wieman, C. (2007). Why not try: A scientific approach to science education? *Change*, *39*(5), 9-15.

Whitman, N. (1990). *Creative medical teaching*. Salt Lake City, UT: University of Utah School of Medicine.