https://doi.org/10.36315/2023v1end137
Education and New Developments 2023

UNCOVERING A PRESUMPTIVE LEARNING PROGRESSION ON ELECTRICITY AND MAGNETISM: A CASE STUDY OF MEANINGFUL SCIENCE TEACHING AND LEARNING IN SOUTH AFRICAN HIGH SCHOOLS

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Abstract

In the subject of science education, debates on topics such as "learning progression," "conceptual transformation," and "meaning making" have a long history, but they remain a vitally significant contemporary issue. Learning progression (LP) is a strategy designed to enhance three components of education: teaching and learning, assessment, and curriculum design. This study focused on building a learning progression of electricity and magnetism concepts that outlines how high school science students develop a more comprehensive grasp of electricity and magnetism concepts after instruction in order to depict a coherent progression of their conception. The constructivism theory and the conceptual change theory served as the theoretical underpinnings for this study. Using a mixed-methods research approach, science teachers and learners from three high schools were purposefully sampled. Interviews, document analysis, and learners' artefacts were used to collect data. The data were coded to characterise teachers' classroom practices and learners' learning experiences in order to ascertain learners' comprehension of the taught big ideas and their application to similar situations. The findings show that learners the high schools can incorporate concepts regarding electricity and magnetism to form a framework for learner understanding of these concepts if they receive appropriate instructional support.

Keywords: *Electricity and magnetism, learning progression, physical sciences, science learners, science teachers.*

1. Introduction

Current research on learners' foundational ideas and practices of a discipline develops over time focuses on how students learn, progress, or change in specific areas of knowledge (Jin, et.al., 2019). Debates around issues such as "learning progression", "conceptual change" or "meaning making", have a long history, but they remain a very important topical issue in the field of education (Brown, Bransford, & Cocking, 1999).

Learning progression (LP) articulates a trajectory of learning and understanding in a domain in the form of levels or steps in learner understanding toward proficiency (Alonzo, & Elby, 2019). In the same disposition, LP has been developed in many areas, including languages (Harden, Witte, & Köhler, 2006), mathematics (Seah, & Horne, 2020) and science (Stevens, Delgado, & Krajcik, 2010). By articulating a trajectory of learning and understanding in a domain, LP provides broad spectrum of ideas on what and how learners are to learn, the varied instructional strategies to be adopted and implemented by the teachers and provide guidelines for the design of learner assessments.

Learning progressions in science are empirically grounded and testable hypotheses about how learners' understanding of scientific concepts and their ability to use and explain these core concepts which are related to scientific practices grow and become more sophisticated over time, with appropriate instruction (NRC, 2007). In a study that was carried out in the United States of America related to learning progressions in high school chemistry (Stevens, Delgado, & Krajcik, 2010), and in Italy (Testa et al., 2019) towards a hypothetical learning progression of scientific explanation, all show the synthesis of a cross-age account of learners' conceptual grasp and development of scientific concepts in the form of a learning progression. In the large number of empirical studies related to concepts on learning progression conducted by researchers over the past decades, the most frequently discussed topics in the field of physics are related to mechanics, dynamics, and energy (Lee, et al., 2017). However, one core concept that learners need to understand in order to be able to explain scientific phenomena in relation to our technological world is the concept of electricity and magnetism. Research in the field has shown that, most of the learners did not show any significant learning of the basic concepts of electromagnetism even after been exposed to instructions (Michelini, et al., 2007).

Although, the content of the concept of electricity and magnetism are different at all levels of the educational ladder, this does not mean that the conceptual understanding of learners in these concepts would be the same at all levels of teaching. These concepts become more complex in years of learning and teaching, but for most learners they are still far from scientific representations. Most of the studies I reviewed focused on analysing learners' concepts in specific areas, such as the interaction behind the abstract concepts such as electric field, flux, magnetic induction between magnets across all grades, distinctions between the concepts of charge and fields and conceptual difficulties (Li & Singh, 2019). However, few studies provide a more extensive analysis that includes the matter the magnetic material is made of, magnetic fields and how magnetic forces do work (Onorato & De Ambrosis, 2013). These studies explain some of the characteristics of the learners' misconceptions and difficulties of electricity and magnetism, but do not involve the learners' conceptual development and understanding of electricity and magnetism to describe a coherent progression. In addition, few studies appear to have been done to investigate across ages and grades the longitudinal progression of learners' conceptual development and understanding of Electricity and Magnetism.

Against this background, this project intends to develop a LP to describe how high school learners builds more complex understanding of those concepts of electricity and magnetism that support understanding of these concepts to describe a coherent progression of learner conceptions to inform instruction. The following research questions guided the study:

1. How do learners progress in their understanding of electricity and magnetism from grade 10 through grade 12?

2. Literature

2.1. Conceptualising learning progression

Learning progression (LP) is an approach that aims to support three aspects of education: teaching and learning, assessment, and curriculum design. According to Schmidt, Wang, and McKnight (2005) the effectiveness of these three aspects of education may be increased by better coherence, and the LP approach claims to improve coherence by providing frameworks of knowledge and skills called "LP models". These models describe the progression that can be expected of learners through their education. Schmidt et al., (2005) reviewed results of Third International Mathematics and Science Study (TIMSS) and found that countries achieving higher at these international exams have implemented a coherent curriculum framework.

To help develop a coherent framework to guide science education, the South African department of Basic Education adopted and implemented the National Curriculum and Assessment Policy Statements (CAPS) for Physical Sciences for Grades 10 to 12 in 2012. Central to the CAPS curriculum principles is the idea of learner progression, which describes the learning progression of learners in the content and context of each grade to show a progression from simple to complex concepts in physical sciences (DoE, 2011). This means that teachers must adopt strategies for effective teaching and learning, ensuring that learners make meaning as they move from simple information to complex materials in the teaching-learning process whiles relating one core idea to another in a particular concept. Of paramount is the idea that LP does not focus solely on the end product of understanding of concepts but also illustrates how ideas build upon one another to create new levels of understanding (NRC, 2007). The CAPS document for physical sciences, therefore, incorporates learning progression, which is organised around six core strands to help describe the knowledge and skills learners need to develop whilst promoting knowledge and understanding of the concept and its interrelationships to technology, society and the environment at large (DoE, 2011). In this study, I used such a model of learning from simpler to more sophisticated to develop LP of electricity and magnetism to guide learners to develop a meaningful understanding of these concepts as they progress successfully through schooling.

Table 1. Main concepts that have been included in the learning progression for electricity and magnetism.

Electricity and Magnetism	**Grade 10**	Magnetism (magnetic field of permanent magnets, poles of permanent magnets, magnetic field lines), Electrostatics (two kinds of charge, the force exerted by charges on each other (descriptive), an attraction between charged and uncharged objects, charge conservation, charge quantization), Electric circuits (emf, potential difference, current, measurement of voltage and current, resistance, resistors in parallel).
	Grade 11	Electrostatics (Coulomb's Law, Electric field), Electromagnetism (Magnetic field associated with current-carrying wires, Faraday's Law), Electric circuits.
	Grade 12	Electric circuits (internal resistance and series-parallel networks), Electrodynamics (electrical machines (generators, motors), alternating current) 12 hours

(Source: Department of Basic Education, CAPS, 2011)

3. Research methods

Taking the stances of McCoy (2015) who advocates for the use of mixed research methods, an exploratory research design was followed. A purposeful sampling technique was used to select the participants from grades 10 through grade 12. A total of 210 participants were recruited to take part in this longitudinal study. Data sources were obtained from questionnaires, written responses, interviews, and classroom observation notes.

Data collection commenced in the 3rd quarter of 2022, when most schools taught the topics of Electricity and Magnetism. Data was collected in 4phases. LP was developed incorporating ideas from the big ideas listed in the table below. Details of the LP will be published elsewhere.

Table 2. Big ideas contained in the concepts included in the learning progression for electricity and magnetism.

	Big Ideas	**Contents**	**Knowledge levels**
Sub-concepts	Magnetism	Magnetic field of permanent magnet, poles of permanent magnets, attraction and repulsion, magnetic field lines, earth's magnetic field, compass),	All levels of cognitive processes (1, 2, 3, 4 &5)
	Electrostatics	Two kinds of charge, force exerted by charges on each other (descriptive), attraction between charged and uncharged objects (polarisation), charge conservation, charge quantization), Coulomb's Law, Electric field),	
	Electric circuit	Electric circuits (emf, potential difference current, measurement of voltage and current, resistance, resistors in parallel), Energy, Power), internal resistance and series-parallel networks),	
	Electromagnetism	(Magnetic field associated with current-carrying wires, Faraday's Law),	
	Electrodynamics	Electrical machines (generators, motors), alternating current).	

The researcher believes that students of all grade levels can incorporate concepts from multiple concepts when discussing phenomena. As they advance through the LP, their explanations will become increasingly sophisticated and less scientifically accurate. Learners incorporate new concepts as they progress through the LP to develop increasingly intricate models that characterise the concept of electricity and magnetism.

Using the instruments designed, data was collected. To ensure the reliability and validity of the instruments, all the instruments were given to experts in the field to determine whether the instruments covered the contents intended to cover. The reliability of the instruments was also determined using Cronbach's alpha. All instruments were piloted to increase their reliability. Both numerical and qualitative responses were triangulated to ensure validity. The interview dataset was transcribed and sent out to participants for member checking. Interview data were coded to characterise learners' responses to question items on electricity and magnetism to demonstrate ideas behind their responses. Classroom observations were coded to characterise teachers' teaching practises and learners' experiences using thematic analysis.

4. Findings

4.1. Teachers' practices and experiences with the LP

The findings show that teachers start their lessons with learning goals and use various teaching methods in their classroom instructions. It was also observed that most classroom instruction was basically a lecture method where learners become passive participants in the teaching-learning process. Sometimes teachers demonstrated activities for learners to grasp the big ideas behind the text. In addition, teachers sometimes relate the lesson to real-life scenarios and capitalise on learners' prior knowledge as they make connections between big ideas on electricity and magnetism. In contrast, teacher content knowledge gaps were also observed in some of the lessons where teachers were unable to represent science content or processes and improper use of teacher questioning, prompting and providing feedback. When the teachers were interviewed, they indicated that electricity and magnetism are challenging concepts for learners to grasp. The reason is that the concepts of electricity and magnetism are exceedingly abstract. Therefore, the learners have trouble comprehending them. In addition, all the teachers appeared to concur that the most challenging aspect of electricity and magnetism is the abstract nature of which they are represented. The teachers were of the view that the learners could not conceptualise abstract concepts such as internal resistance and magnetic flux. One teacher lamented:

> *Learners find it difficult to conceptualise the concept of magnetic flux as they presume it to be too abstract.* (Mr Ndovela)

The teachers were of the view that some concepts on electricity and magnetism, specifically electromagnetism lesson, are fascinating to the learners because it has numerous applications in everyday life, including the motor effect, generators, and transformers. However, they acknowledged that these applications are not expressly discussed in class, as the majority of the lesson focuses on quantitative problems, which are challenging for learners. One teacher narrated:

> *Learners have anxiety when it comes to the working functioning of motors and generators and find it difficult to answer questions about induced e.m.f. in a coil when a magnet is moved in or out or a nearby coil's current is switched on or off may be cause for concern.* (Mr Sisthi)

In contrast, the performance on the remaining test questions dealing with slightly less fundamental concepts or requiring the application of fundamental concepts is less satisfactory.

4.2. Learners' learning progressions

Although the researcher did not analyse all data to be included in this paper, the initial dataset indicated learners' ideas and conceptual growth on electricity and magnetism vary.

Learners' responses and artefacts on electricity and magnetism show conceptual growth. In all, most learners were able to give a reasoning behind the question posed to draw big ideas from them. For example; learners were able to explain that when a magnet moves into a coil of wire, a potential difference is induced across the ends of the coil; if the magnet is moving out of the coil, or if the other pole of the magnet is moving into it, the opposite potential difference is induced. Few learners were able to indicate that the changes in the current in one coil of wire can elicit a voltage in a neighbouring coil by inducing a fluctuating magnetic field.

The artefact from the learners shows diagrams they used to indicate a simple transformer, with all its parts and components indicated, with two wire coils wound on an iron core. With the artefact, learners were able to explain that a changing current in one coil of a transformer will induce a changing potential difference across the other transformer coil. However, very few learners were able to explain that a magnet or electromagnet is rotated within a wire coil to induce a voltage across the extremities of the coil in a generator, with understanding. Furthermore, few learners were able to explain the revolution of the magnets as they explained that, during each revolution of the magnet or electromagnet, the induced voltage across the coil of an alternating current generator (and, consequently, the current in an external circuit) changes.

5. Conclusion and recommendation

The findings presented suggest that the theory of learning inherent to the LP approach is helpful because it does not reflect the inconsistencies and complexities of the actual process of change that learners go through or how inconsistently they can demonstrate their learning. Hence, the implementation of a theory based on the ladder analogy, replacing other approaches and models of learning, is therefore likely to be counterproductive for learning. This is not to say that no learner progresses or that simplifications cannot be useful in certain contexts (such as when creating a scheme of work from a curriculum), but that the theory described by "Learning progressions" authors if implemented without additional curriculum and learning consideration, would not result in positive educational outcomes. High school learners can provide relatively sophisticated descriptions of electricity and magnetism according to these findings. Students in high schools can incorporate concepts regarding the concept of electricity and magnetism at the molecular level when given the appropriate instructional support.

Acknowledgements

The author gratefully acknowledges the financial support provided by the WSU Seed Fund for the completion of this research project.

References

Alonzo, A. C., & Elby, A. (2019). Beyond empirical adequacy: Learning progressions as models and their value for teachers. *Cognition and Instruction*, *37*(1), 1-37.

Brown, A. L., Bransford, J., & Cocking, R. R. (1999). *How people learn: Brain, mind, experience, and and School.* Washington, DC: The National Academies Press. https://doi.org/10.17226/9853

Department of Education. [DoE] (2011). *National Curriculum Statement Grades R - 12: Curriculum and Assessment Policy (CAPS) Physical Sciences*. Pretoria.

Harden, T., Witte, A., & Köhler, D. (2006). *The concept of progression in the teaching and learning of foreign languages*. Peter Lang.

Jin, H., Mikeska, J. N., Hokayem, H., & Mavronikolas, E. (2019). Toward coherence in curriculum, instruction, and assessment: A review of learning progression literature. *Science Education*, *103*(5), 1206-1234.

Lee, K., Dong, H., Choi, W., Kwon, G., Lee, I., & Kim, Y. J. (2017). Exploring a learning progression for eight core concepts of middle school science using constructed response items in the National Assessment of Educational Achievement (NAEA). *Journal of Science Education*, *41*(3), 382-404.

Li, J., & Singh, C. (2019). Investigating and improving introductory physics students' understanding of electric field and the superposition principle: The case of a continuous charge distribution. *Physical Review Physics Education Research*, *15*(1), 010116.

McCoy, D. L. (2015). Mixed Methods Research. In F. K. Stage, & K. Manning (Eds.), *313 Research in the College Context: Approaches and Methods* (pp. 105-118). London: Routledge

Michelini, M., Mossenta, A., Testa, I., Viola, R., & Testa, A. (2007). Teaching Electromagnetism: Issues and changes. In *Proceedings of the Girep/EPEC 2007 Conference on Frontiers of Physics Education* (pp. 33-37).

National Research Council. [NRC] (2007). Generating and evaluating scientific evidence and explanation. In R. Duschl, H. Schweingruber, & A. Shouse (Eds.), *Taking science to school: Learning and teaching science in grades K–8* (pp. 129–167). Washington D.C.: National Academies Press.

Onorato, P., & De Ambrosis, A. (2013). How can magnetic forces do work? Investigating the problem with students. *Physics Education*, *48*(6), 766.

Schmidt, W. H., Wang, H. C., & McKnight, C. C. (2005). Curriculum coherence: An examination of US mathematics and science content standards from an international perspective. *Journal of curriculum studies*, *37*(5), 525-559.

Seah, R., & Horne, M. (2020). The construction and validation of a geometric reasoning test item to support the development of learning progression. *Mathematics Education Research Journal*, *32*, 607-628.

Stevens, S. Y., Delgado, C., & Krajcik, J. S. (2010). Developing a hypothetical multi-dimensional learning progression for the nature of matter. *Journal of Research in Science Teaching*, *47*(6), 687-715.

Testa, I., Capasso, G., Colantonio, A., Galano, S., Marzoli, I., Scotti di Uccio, U., ... & Zappia, A. (2019). Development and validation of a university students' progression in learning quantum mechanics through exploratory factor analysis and Rasch analysis. *International Journal of Science Education*, *41*(3), 388-417.