Available Online at www.e-iph.co.uk
Indexed in Clarivate Analytics WoS, and ScienceOPEN

E-B
Environment - Behaviour
Proceedings Journal

AQoL2023Bali
https://www.amerabra.org

e-IPH
e-International Publishing House Ltd., United Kingdom

07th Asia-Pacific International Conference on Quality of Life
Wina Holiday Villa, Kuta, Bali, Indonesia, 30 Sep – 02 Oct 2023

Development of a Learning Progression Assessment Tool for Electrostatics Utilizing the Rasch Model

Sun Dehui[1], Sheiladevi Sukumaran[2*], Gao Song[3]
* Corresponding Author

[1] Department of Fundamental Education, Shandong Jiaotong University, Weihai, China ,
[2] Faculty of Education, Language, and Psychology, SEGi University, Petaling Jaya, Malaysia
[3] Faculty of Physics and Electronics, Shandong Normal University, Jinan, China

sdhsdjt2018@163.com, sheiladevisukumaran@segi.edu.my, gaosong@sdnu.edu.cn
Tel: +60 1123176520

Abstract
The Learning Progression (LP) model has gained significant attention in science education due to its successful integration of students' cognitive development with scientific concepts. This study aims to address the challenges of delivering the electrostatic field topic in physics education at the tertiary level, where students often find it abstract and challenging to grasp. To create a tailored electrostatic LP model suitable for this educational level, appropriate teaching tools were developed. The Electrostatic Field Test (EFT) was devised and subjected to validation using Rasch models. The validation results affirm the EFT's reliability and validity.

Keywords: Learning Progression, Rasch Model, Physics teaching and assessment

DOI: https://doi.org/10.21834/e-bpj.v8i26.5195

1.0 Introduction

The learning Progression (LP) model provides a framework for understanding the progression of students' learning in a specific domain, allowing educators to identify gaps in knowledge and tailor instruction accordingly. Built upon students' cognitive development and thinking processes, this model combines scientific concepts with learning approaches using a dual approach of top-down and bottom-up methods. In fact, the problems related to LP have long been discussed in the history of curriculum development (Alonzo, 2012). Bruner has long proposed the spiral curriculum structure, which is intended to solve the problem of teaching sequence (Berland, 2010). The learning progression model in physics education aims to provide a structured framework for understanding and assessing students' progress in mastering electrostatic concepts. Applying the LP model aids teachers in designing effective teaching strategies that foster students' deep understanding, critical thinking, and problem-solving abilities, preparing them for real success.

This study addresses the challenges in learning electrostatics in physics subjects, as students commonly find the subject abstract and challenging to comprehend. Therefore, it is essential to construct a learning progression model specifically for electrostatics. However, the need for corresponding survey data during the model's construction highlights the importance of developing appropriate measurement tools. Based on existing scales and test items, this study developed an Electrostatics Feedback Questionnaire (EFQ) and an Electrostatics Test (EFT). In this study, a pilot study was conducted using SPSS and Rasch models to evaluate the reliability and validity of testing instruments. The results showed that these instruments are suitable for further research. The findings of this study

DOI: https://doi.org/10.21834/e-bpj.v8i26.5195

have significant implications, to improve the teaching of electrostatics and enhance students' understanding and application of the subject matter.

2.0 Literature Review

2.1 Learning Progression

Establishing the relationship between reality and abstract concepts proves challenging for many students, leading to suboptimal learning outcomes (Salinas, 2009). Roseman (2006) highlights that learning progression (LP) represents a logical "concept sequence" extending from primary to high school and aligning with students' developmental stages. The National Research Council of the United States defines LP as a coherent and gradually deepening thinking path that students traverse when learning and studying a topic over an extended period (Linda Morell, 2017). Merrit (2008) describes LP as the process through which students progressively understand concepts in a field, transitioning from shallow to deep and increasingly complex levels.

In actual research, people's viewpoints can be broadly categorized into two main types (Gao, 2020): one perspective is preconceived, often referred to as "from top to bottom". Those who hold this perspective believe that the progression of learning follows a "sequence of conceptual development" or a "pathway of conceptual development". Thus, according to this view, the progression of learning aligns with the logical development of disciplinary knowledge. This approach allows the framework for progression to be derived from the disciplinary framework itself, based on the subject's knowledge structure. The other perspective is based on educational reality, often referred to as "from bottom to top". Advocates of this viewpoint believe that progression reflects learners' performance at different stages of learning. Scholars who hold this perspective, such as Schwarz, believe that the manifestation of learning progression lies in the construction and development of models during the learning process(Schwarz et al., 2009). Linn argues that the manifestation of learning progression is associated with changes in the features of knowledge interconnections(Linn, 2006). However, regardless of the perspective, two main issues exist: firstly, the oversimplification of defining learning progression. The former focuses on discussing learning progression in the context of curriculum, while the latter addresses learning progression in the context of assessment. Although some literature attempts to integrate the two, their interrelation has not been adequately clarified. Secondly, there is a lack of a reasonable explanation for the mechanism of learning progression. Consequently, the interpretations of progression lack deep theoretical support and appropriate explanatory models. This may lead to research conclusions being highly arbitrary and constrained, making it difficult to verify and adapt in other studies, especially in the application of teaching regarding learning progression (Gao, 2020).

2.2 Electrostatic Field Learning

In the field of physics, the electromagnetic field stands in contrast to the concrete nature of mechanics. The electromagnetic field, unlike mechanics, is abstract, yet it reflects the essential concept of electromagnetism (Feynman, 2013). Fundamental ideas in electromagnetism, such as Coulomb's law, charge conservation, electric field strength, and electric potential energy, are critical to understand the subject's key and challenging aspects (Dehui, 2018). However, due to the abundance of physical quantities, definitions, formulas, and abstractions, students often struggle to grasp these concepts accurately. Relying on rote memorization and superficial understanding hinders their ability to comprehend the underlying principles effectively (Roseman, 2017).

The study of the electrostatic field addresses a unique obstacle for educators and students. Consequently, students usually develop a mental model of the electrostatic field by observing its effects on surrounding objects. Constructing this mental model requires abstract thinking skills, which can be accustomed to more tangible approaches, such as those employed in mechanics. Furthermore, the electrostatic field operates differently from the mechanical world, possessing distinct properties like non-contact interaction at a distance. To overcome these challenges, teachers must carefully design instructional methods that facilitate students' comprehension of the abstract nature of the electrostatic field. Students must develop the ability to think abstractly, construct a physical model based on observable effects, and appreciate the fundamental disparities between the electrostatic and mechanical realms. With proper guidance and effort, students can acquire the abstract thinking skills necessary to construct a robust mental model of this intricate field, equipping them for future scientific endeavors.

3.0 Methodology

3.1 Instrumentation

This study employs the Rasch model to evaluate the measurement instrument and the structure of the measurement scale using a representative data set collected from the Electrostatic Field Test (EFT).

The Electrostatic Field Test (EFT) is utilized to assess the participants' actual learning progress and performance quantitatively. Besides, the items were obtained from the world-widely used CSEM (Conceptual Survey of Electricity and Magnetism) test, which is internationally recognized. To obtain permission to use the test, the researcher registered on the official website of the American Association of Physics Teachers and successfully obtained researcher identity authentication. With the granted permission to use the CSEM test, the researcher then modified and supplemented certain items to align with the specific requirements of this study. Additional questions were included to assess students' understanding of scientific methods and mathematical tools tailored to the learning context of students in Shandong Province, China.

3.2 Sampling
The quantitative aspect of the study relies on probability sampling, which entails selecting individuals from the population to participate in the research (Chua, 2016). Creswell (2008) suggests that quantitative research is suitable for exploring diverse research ideas and elucidating the intricacies of different populations, and surveys facilitate comprehension of the research topic. Furthermore, Creswell and Clark (2001) emphasize the significance of maximal variation sampling, a purposeful sampling method that involves selecting research participants based on specific characteristics.

This study was conducted at Shandong Jiaotong University (SJU) in Weihai, Shandong Province, China. Random sampling is utilized in this procedure. SJU is a comprehensive university jointly established by the Ministry of Transport of the People's Republic of China and the People's Government of Shandong Province. In this study, the sample was chosen by implementing a random sampling method, guaranteeing an impartial and equitable population representation. The following section comprehensively describes the student sampling procedure employed during the data collection phase. The steps involved in the simple random sampling technique are depicted in Figure 1 below.

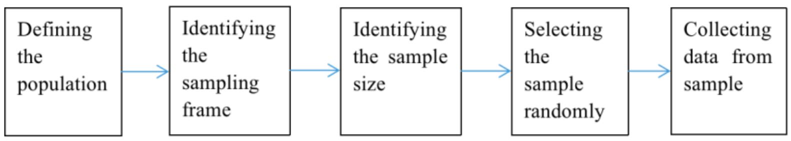

Fig. 1: Steps in the Sampling Procedure

A pilot study, also known as a feasibility study, can be described as a small-scale investigation or trial that explores potential research methods, materials, tools, coding sheets, and analytic approaches that researchers may employ in a larger research project (Gass & Mackey, 2012). Prior to the commencement of the main research, a preliminary study was conducted involving 85 students. These participants were chosen using a random sampling technique, which was consistent with the sampling method employed in the subsequent formal study. The objective of the pilot study was to assess the reliability, validity, and other parameters of the Electrostatics Test (EFT), thus validating its effectiveness for future measurements and research purposes.

3.3 Data collecting and analysis.
The Electrostatic Field Test (EFT) is analyzed using the Rasch model, which is implemented through the Winsteps software. The Rasch model, a widely used item response theory model, assesses the difficulty levels of test items and participants' abilities. This analysis facilitates the determination of item difficulty levels and the evaluation of participants' relative abilities. Before conducting the data analysis, any invalid test items and unreasonable data are removed to ensure the accuracy of the analysis results.

The development of the Electrostatic Field Test (EFT) involved extracting electrostatics-related questions from the Conceptual Survey of Electricity and Magnetism (CSEM), an internationally recognized assessment. Certification from the American Association of Physics Teachers was obtained for this purpose. Additional questions covering scientific methods and mathematical tools were included to assess students' understanding and application of electrostatics comprehensively. The EFT consists of three parts: the core concepts section (QCC), comprising questions Q1 to Q18, the scientific methods section (QSM), including questions Q19 to Q30; and the mathematical tools section (QMT), encompassing questions Q30 to Q38.

In the analysis of the Electrostatic Field Test (EFT), the initial step involved identifying identical responses through correlation analysis conducted using the Rasch model software, Winsteps. Subsequently, highly correlated responses were compared based on their original answers. If the answers were nearly identical, those cases were excluded from the analysis. Additionally, outliers were examined during the Rasch analysis. The Rasch measurement considers the probability of a test-taker providing a correct response to an item based on their individual parameter (ability) and the item parameter (difficulty). If the response pattern significantly deviated from the model's expectations, it raised concerns regarding the test-takers' engagement. Outliers, indicated by outfit and infit values beyond the range of 0.5-2, were selected and manually examined to assess the reliability of their responses.

3.4 Reliability and Validity
In research, the concept of reliability refers to the extent to which the findings can be replicated. What matters more in research is the consistency of approaches used by different researchers and in different projects (Creswell & Creswell, 2018). Lincoln and Guba (1985) were early proponents of referring to reliability in research as consistency or dependability.

The reliability analysis of the static field test items was conducted using Rasch analysis. The collected items were analyzed using the Winsteps software. According to Li Xiaofeng (2022), reliability analysis using the Rasch model encompasses three aspects: Reliability, Separation, and Model error (Model S.E.), as presented in Table 1.

Table 1: Reliability Analysis of Rasch Model

Reliability Analysis	**Index**	**Range**
	Item and person Reliability	Item reliability and subject reliability are measured

		on a scale from 0 to 1, with values closer to 1 indicating better reliability
	Separation	Values greater than 2 indicate a higher level of differentiation in the abilities of the subjects. A larger value suggests a greater disparity in proficiency levels among the participants
	Model S.E.	The values range from 0 to 1, and a value closer to 0 is preferable for better reliability

Validity refers to the extent to which measurement tools or methods accurately assess the intended constructs or phenomena (Gay et al., 1993). According to Gay (1993), content validity holds significant importance in achievement tests. If a test score fails to capture what a student has learned and what they are expected to retain, it cannot accurately reflect their level of achievement.

The test responses will be analyzed using the Rasch model, with a primary focus on the Wright map and one-dimensional measurement for the validity analysis (Li, 2022). Table 2 provides an overview of these validity analysis measures.

Table 2: Validity Analysis of Rasch Model

	Index	Range
Validity Analysis	Wright map	A distribution that is closer to a normal distribution is considered preferable.
	One-dimensional	The values typically range between -0.4 and +0.4.

4.0 Findings

4.1 Reliability Analysis

These reliability indices provide valuable information about the consistency and stability of both the test items and the individuals' responses. Table 3, Table 4, and Table 5 presented the reliability and separation indices for the questions related to core concepts (QCC), scientific methods (QSM), and mathematical tools (QMT) respectively, providing an overview of the reliability analysis for each question.

Table 3: Reliability and Separation of QCC

	TOTAL NUMBER	MEASURE MEAN	RELIABILITY	SEPARATION
ITEMS	18	0.00	0.72	1.43
PERSONS	80	-0.21	0.87	1.81

Table 4: Reliability and Separation of QSM

	TOTAL NUMBER	MEASURE MEAN	RELIABILITY	SEPARATION
ITEMS	12	0.00	0.75	1.35
PERSONS	80	-0.22	0.78	1.36

Table 5: Reliability and Separation of QMT

	TOTAL NUMBER	MEASURE MEAN	RELIABILITY	SEPARATION
ITEMS	8	0.00	0.77	1.84
PERSONS	80	-0.58	0.78	0.63

4.2 One-dimensional

By examining these indices, we can gain insights into the extent to which the items in the test measure the same dimension. A higher proportion of variance explained by the Rasch model scores indicates a greater likelihood of the items measuring the same underlying dimension. The correlation indexes can be observed in Figure 2, Figure 3, and Figure 4, which provide valuable information for assessing the one-dimensionality of the test.

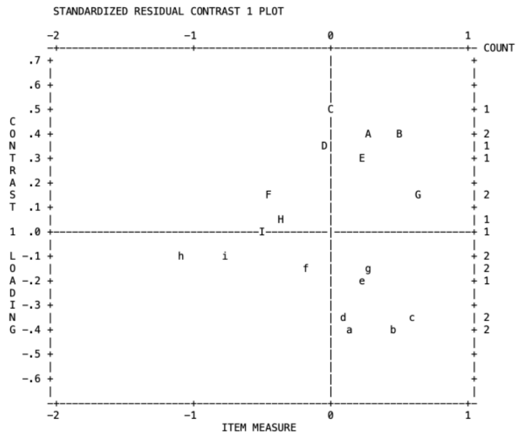

Fig. 2: One-dimensional map of QCC

In the map above, the horizontal axis in the graph represents item difficulty, while the vertical axis represents the correlation between item scores and the measured construct. Each letter represents a specific item. The vertical values of correlation indexes range from -0.4 to 0.4, indicating that the one-dimensional of the items meets the requirements. It can be observed that almost all items fall within the normal range, except for item C, which has a value of 0.5, slightly higher than the standard of 0.4. But, it was still acceptable.

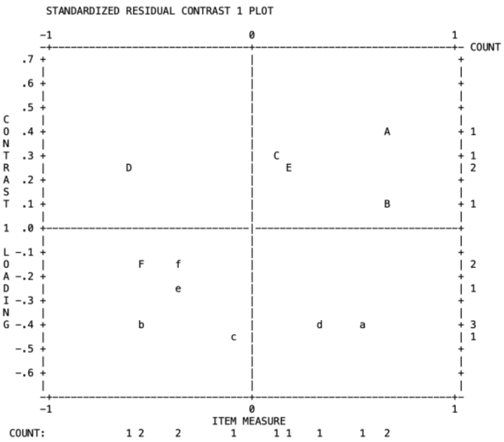

Fig. 3: One-dimensional map of QSM

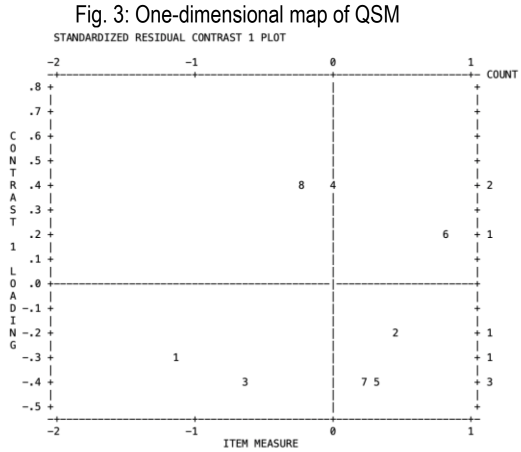

Fig. 4: One-dimensional map of QMT

From Figures 3 and 4, it can be seen that all the correlation coefficients fall within the standard range of -0.4 to 0.4. Additionally, all the items were evenly distributed on both sides of the vertical zero line, further confirming that the MEASURE MEAN of this test was 0.

4.3 Wright-Map

According to Hughes (1989), the Rasch model offers a significant advantage by directly comparing item difficulty and student ability on the same measurement scale. In the Wright Map, the left represents student ability, while the right represents item difficulty. The items were arranged in descending order of difficulty, with the easiest items at the top and the most difficult items at the bottom. The White-Maps of QCC, QSM, and QMT can be observed in Figure 5, providing a visual representation of the relationship between student ability and item difficulty.

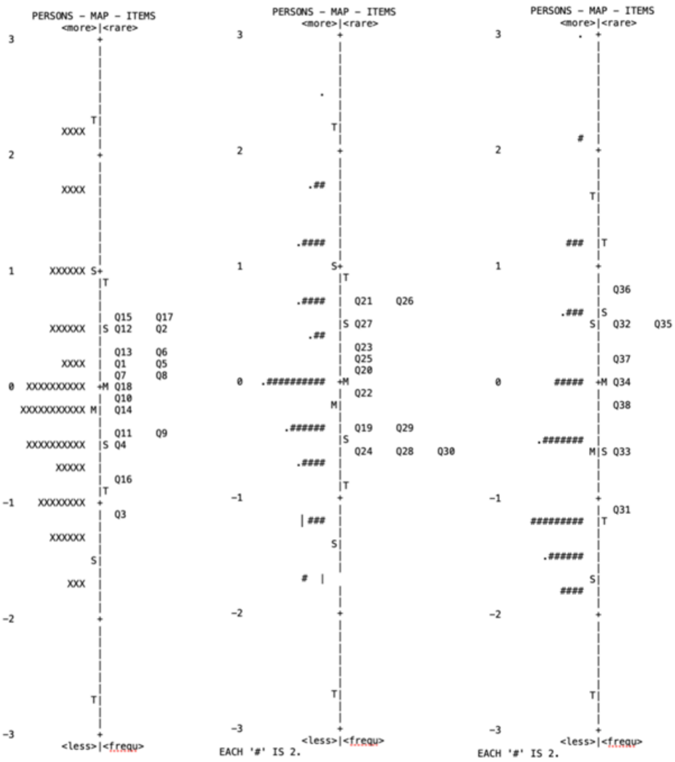

Fig. 5: Wright-Maps of QCC, QSM and QMT

By examining the three figures above, it was evident that the average difficulty of the test items and the average ability of the students exhibit similar distributions. This implies that the overall difficulty of the test is moderate and demonstrates good differentiation among the students' abilities. Specifically, the left scale, representing student ability, was slightly lower overall, indicating that the average level of the students was slightly below the mean. Conversely, the right scale, representing item difficulty, was centered, with the test items evenly dispersed around the zero mark. This indicates a moderate average difficulty level for the items.

5.0 Discussion

Several important conclusions about electrostatics have been gained based on the data analysis performed in this Electrostatic Field Test (EFT) pilot study. These findings help to evaluate and validate the pilot study's findings, providing insights for the upcoming official study's design and data gathering. To begin, the measurement tools utilized in this study have shown outstanding dependability, suggesting their ability to deliver trustworthy data across different time points and samples consistently. This great reliability provides a solid basis of trustworthy data for the research.

Second, the design of these measuring equipment has been carefully considered. They effectively cover the core concepts of electrostatics without overwhelming students with excessive information or insufficient test content. This attentive item design ensures the measurement tools' usefulness and accuracy. This moderate difficulty level helps stimulate students' thinking and interest in learning while effectively differentiating their abilities.

In conclusion, the EFT sections of this pilot study present reliable and effective measurement tools for accurately assessing students' abilities and knowledge in the field of electrostatics. These findings establish a strong foundation for our subsequent formal research and offer valuable insights for educational practices.

6.0 Conclusion& Recommendations

In conclusion, the study has contributed to a deeper understanding of their educational journey by exploring the cognitive development and learning progression of students. The learning progression model established in this research provides valuable insights for educators to tailor their teaching strategies and optimize the learning experience. Teachers could follow the LP model in order to make clear the situation of students. This leads to the improvement of physics teaching.

Moving forward, several recommendations emerge. Firstly, expanding the sample size and diversifying the participant demographics will enhance the generalizability of the findings. Secondly, ongoing refinement of the measurement tools is essential to capture the full spectrum of cognitive development accurately. Thirdly, cross-disciplinary collaboration can further enrich the study of learning progression. Lastly, longitudinal research can offer a more comprehensive view of students' cognitive growth over time.

Acknowledgment

We extend our heartfelt gratitude to all those who supported and contributed to the realization of this research endeavor. Our sincere appreciation goes to our advisors and mentors for their guidance, insights, and expertise which have been invaluable throughout this journey. We also express our thanks to the participants whose cooperation and willingness made this study possible.

Paper Contribution to Related Field of Study

This paper significantly contributes to the field of educational research by presenting a robust Physics Learning Progression Assessment Tool for Electrostatic Fields. By integrating cognitive development theories and measurement methodologies, this study enriches the understanding of learning progression. The established model offers educators a comprehensive framework to better comprehend students' cognitive growth and to optimize pedagogical strategies. Furthermore, the insights gained from this study have the potential to influence educational practices and curricular design, fostering more effective teaching and learning approaches.

References

Christina V. Schwarz, Brian J. Reiser, Elizabeth A. Davis, et al. (2009). Developing a learning progression for scientific modeling: Making scientific modeling accessible and meaningful for learners. *Journal of Research in Science Teaching, 46*(6).

Chua, Y. (2016). Mastering research methods. *McGraw-Hill Education*. New York.

Creswell, J. W., & Creswell, J. D. (2017). Research design: Qualitative, Quantitative, and Mixed Methods Approaches. SAGE Publications.

Creswell, J. W. & Creswell, J. D. (2018). Research design: qualitative, quantitative,and mixed methods approaches. California: Sage Publications.

Feynman, R. P., Leighton, R. B., & Sands, M. (2013). The Feynman lectures on physics. Basic Books. New York.

Gao, S. (2020). Research on the Mechanics of Learning Progression Based on Psychological Occurrence. Shandong Normal University Journal (Social Sciences), 2020(1).

Gass, S. M., & Mackey, A. (2012). Data elicitation for second and foreign language research. Routledge.

Gay, G. (1993). Building Cultural Bridges: A Bold Proposal for Teacher Education. Education and Urban Society, 25(3), 285–299. https://doi.org/10.1177/0013124593025003006.

Hughes, A. (1989). Testing for language teachers. Cambridge: Cambridge University Press.

Li, X. (2022). The Study on the Learning Progressions of Understanding the Core Ideas of Matter for Students in Compulsory Education. Unpublished doctoral dissertation. Northeast Normal University, Changchun, China.

Lincoln, Y. S., & Guba, E. G. (1985). Naturalistic inquiry. SAGE.

Linn, M. (2006). The knowledge integration perspective on learning and instruction. In R. K. Sawyer (Ed.). *The Cambridge handbook of the learning sciences* (pp. 243-264). New York: Cambridge University Press.

Morell, L., Collier, T., Black, P., & Wilson, M. (2017). A construct-modeling approach to develop a learning progression of how students understand the structure of matter. *Journal of Research in Science Teaching, 54*(8), 1024–1048. https://doi.org/10.1002/tea.21397.

Merritt, J. D. (2008). Development of a learning progression for the particle model of matter. Arizona State University. https://asu.elsevierpure.com/en/publications/development-of-a-learning-progression-for-the-particle-model-of-m.

Roseman, J. E., Caldwell, A., Gogos, A., et al. (2006). Mapping a Coherent Learning Progression for the Molecular Basis of Heredity. Presented at The National Association for Research in Science Teaching Annual Meeting, San Francisco.

Roseman, J. E., Herrmann-Abell, C. F., & Koppal, M. (2017). Designing for the next generation Science Standards: educative curriculum materials and measures of teacher knowledge. *Journal of Science Teacher Education, 28*(1), 111–141. https://doi.org/10.1080/1046560x.2016.1277598.

Salinas, I. (2009, June). Learning progressions in science education: Two approaches for development. In Learning Progressions in Science (LeaPS) Conference, Iowa City, IA.

Sun, D. (2018). Learning progression on core concepts of electrostatic field in high school physics. Unpublished manuscript. Shandong Normal University, Jinan, China.