Effect of Computer Animations on Students' Understanding of Neural Conduction via Annotated Drawings and Graphical Representations

PRIYAMVADA* AND DEEPSHIKHA**

Abstract

The purpose of this study is to show how use of computer animations in teaching is an effective way of revealing the misconceptions of students about the basic concepts in Biology. Two sample schools—multipurpose urban model and residential rural school—were selected for the study. Students of Class XI of age group 16–18 years (N = 80) participated in this study. A two-stage experiment in the form of drawing sessions—before and after formal technical teaching was conducted following an open-ended interview to explore students' basic understanding and cause of misconceptions about neural conduction. During each drawing session, the children were asked to draw the annotated diagrams and graphical representations of the processes taught on the basis of their own observation and understanding. The drawings and graphs were analysed and categorised based on five levels of the drawing criteria given by Köse (2008). The connections they draw and explanations they give to their drawings depict that they have several misconceptions regarding the concepts of 'Neural Control and Coordination'.

INTRODUCTION

Biology is a unique science which requires observation, creativity and detailed description. In the last several years, conventional approaches of teaching and learning of Biology have underestimated the role of drawing and graphing. The

* *Former PGT Biology*, DM School Bhubaneswar, Department of Education, Regional Institute of Education (NCERT), Bhubaneswar, Odisha.

** *Former JNV Internship Trainee*, Department of Science and Education, Regional Institute of Education (NCERT), Bhubaneswar, Odisha.

learning or doing of Biology without the use of visual representations limits learners' comprehension and analysis. Visual representations are the only way to make the unseen seen and the complex simple (Katz, Barnetz, and Hershkowitz, 2014; Quillin and Thomas, 2015).

Previous studies have explored the children's understanding of 'Organs and Organ Systems' (Carvalho, et al., 2004; Reiss et al., 2002; Rowlands, 2004) but there were limited efforts being made to determine the knowledge construction with the help of annotated drawings and graphs. Andersson, Löfgren and Tibell (2019) clearly stated that there are considerable gaps in our knowledge on children's understanding of the human body structure and functions which requires due emphasis to address their previous knowledge. Learning of Biology in recent years is mostly examination oriented, teacher-centric and passive, wherein the students are least engaged in the process. Research studies throughout the 1980s focused more on eliciting students' alternative conceptions also called preconceptions, misconceptions and alternative frameworks (Djanettea and Fouadb, 2014). But how to diagnose and challenge the alternative conceptions of learners in a teaching context still remains vague. Annotated drawings and graphical representations are one of the effective tools to address the learner's alternative conceptions in Biology. Learners often relate their drawings with their own experiences and understanding (Dempster and Stears, 2014; Óskarsdóttir et al., 2011).

The use of computer animations having annotated drawings and graphs will scaffold learner's basic understanding of the biological processes and promote active learning. In addition, it will minimise the use of valuable classroom time and requires no extra pedagogical efforts for teachers (Kararo and McCartney, 2019). Annotation in scientific drawings and graphs will help learners to interpret the complex processes with detailed information and develop connecting link among concepts (Nielsen, 2014).

Review of Related Literature

The human physiology is one of the most difficult branches of Biology (Chase, 2014; Sturges and Maurer, 2013). The challenges of understanding many physiological systems, including cardiovascular system, respiratory and digestive systems, have been addressed in many recent studies (Reiss et al., 2002; Pelaez, 2005; Ormanci and Oren, 2011). However, little is known about the learning difficulties, in neural anatomy and physiology at introductory level. Students often face difficulties in interpreting the basic concepts such as difference between myelinated and unmyelinated neuron, action potential generation across axon, variables of membrane potential, voltage-time graphs of neural signals, the events occurring during the transmission across the synapse, etc. (Guy, 2012; Michael, 2002; Silverthorn, 2002; Montagna et al., 2010). To overcome these difficulties, some approaches have been introduced which include E-learning through MCQ linked animations (Ruiz et al., 2009; Gookin et al., 2010; Merrienboer and Sweller, 2010; Guy, 2011), internet based instructions (Ayres and Paas, 2007; Cook et al., 2008; Cook, 2009) and use of annotated drawings and graphs. Computer animations will help the learner to create systematic annotated drawings and graphs of various physiological processes in Biology.

Importance of Annotated Drawings and Graphical Representations in Learning Biology

Annotation in drawings refers to a drawing accompanied by some written notes and labelling often made with the purpose to provide detailed description about scientific process (Georghiades, 2004). It helps in summarising the large content of information and develops the material useful for revision during examinations. According to Aggarwal (2001), drawing ensures meaningful and deep learning in Biology. It helps learners to look and examine the details of the biological processes. Drawing is an excellent way to present ones' observations in an appropriate format. It acts as a medium for analysis and synthesis and promotes scientific thinking. At the same time it provides a record of students' work to the teachers. Similar to drawings, graphs are also most commonly used to visually illustrate the data (Slutsky, 2014). Graphs may have several parts depending on their format— a figure number, a caption, a head note, axes and scales. Past studies documented that learners face difficulties with graphical interpretations such as in understanding the *x*- and *y*-axis, assigning and illustrating the relationship between the independent and dependent variables, etc. (Picone et al., 2007; Colon-Berlingeri and Burrowes, 2011). However, if graphical representations are frequently practised in the context of classroom situations, it will promote analytical reasoning skills among learners. Graphs can be used to condense and summarise large data sets in less space. It is an effective tool for displaying experimental findings in the field of Biology (Tairab and Al-Naqbi, 2004; Wainer, 2013; Angra and Gardner, 2017).

Role of Computer Animations in Learning Biology

In science education, the use of visual representations helps the learner to see how science works. It contributes to conceptual understanding and knowledge formation (Evagorou et al., 2015). Previously, the use of visual representations started in the form of photographs, diagrams, tables, charts, etc., and over the years, it has evolved with the new technologies such as advanced digital images, three dimensional models, computer animations, etc. These are effective tools to support cognitive understanding in science (Gilbert, 2010; Wu and Shah, 2004). The use of images in science textbooks (Dimopoulos et al., 2003; Bungum, 2008) and in students' representations or models while studying science (Gilbert et al., 2008; Lehrer and Schauble, 2012) are the initial steps in learning science. But in the current trend, it is not enough to facilitate learning. The complicated processes of life sciences cannot be clearly demonstrated with two-dimensional images. The moving images of the biological processes through computer animations provide sequential information about the events. The use of multimedia tools reduces the efforts of teachers in terms of repetitive drawings of the events of same process. It promotes fast learning in a limited period of time.

Need of Study: Challenges Faced by Students and Teachers

Recent studies have revealed that even after formal teaching and learning of basic concepts of neural conduction, students were found not to be able to explain processes in scientific language, despite having knowledge about them. Before beginning the instruction, students' misconceptions are not taken into account by teachers (Dempsey and Betz, 2001; Aydin, 2012). Simultaneously, the transactional methods used by the teachers are also not relatable at par with the student's misconceptions. The mode of instruction mostly followed was textbook oriented (Figure 1). Various research studies have been conducted to address students' misconceptions by using interviews, open ended questions, two-tiered multiple choice tests, questionnaire based test, etc. However, there were limited studies on how animations including annotated drawings and graphs are used for instructional purpose as well as enhancement of students' basic understanding.

Rationale of the Study

We believe that this approach will facilitate the organisation of knowledge among students in a hierarchical manner. It will help in active construction of knowledge and provide additional resource for learning. We have taken two types of schools intentionally for this study on the basis of location, i.e., rural and urban. It also takes into account the organisational affiliation considering factors that may affect our approach and findings, i.e., previous knowledge of the students, instructional strategies which are being used by the teachers in both types of schools, intelligence level of the students, etc.

Objectives

The objectives of the study are as follows:

- To identify the misconceptions of the students about the topic 'Neural Conduction'.
- To explore whether the use of computer animations enhances

the drawing and graphical skills of the students.

- To compare the drawing and graphical skills of the students of multi-purpose model and residential rural schools.

Research Questions

In this study, we tried to explore the following research questions:

- What are the ways for improving students' annotated drawing and graphical skills on the topic of neural conduction?
- What misconceptions do students perceive before and after instruction about neural conduction?
- Is there any difference in instructional methods which are carried out by subject teachers in both types of schools?
- Is there any difference in the use of teaching aids in both the schools?
- Is the traditional teaching method of schools effective for teaching topics like neural conduction?

Hypotheses

HO1: There will be no significant difference among the students' biological drawings and graphs before instruction and after instruction.

HO2: There will be no significant difference between the students' biological drawings and graphs of Demonstration Multipurpose School (DMS) and Jawahar Navodaya Vidyalaya (JNV) based on the school location.

Methodologies

Research Design

Quasi-experimental research design was followed based on single group pre-test and post-test research model.

Participants

For this study, we have collected the data from 80 students studying in Class XI with subject specialisation—Biology at the Demonstration Multipurpose School, Bhubaneswar, from two sections and Jawahar Navodaya Vidyalaya, Khordha, from one section. The selection of students and sections were done through simple random probability sampling. The sample was composed of 56 female and 24 male students whose mean age was 16–17 years. 40 students were from DMS and 40 were from JNV. All of them had studied about 'Life Processes' and 'Control and Coordination' at the secondary level.

Procedure

We have selected Chapter 21 of Class XI NCERT Biology textbook, that is 'Neural Control and Coordination' for the study. The subtopics which were taught through computer animations were—

- Neuron as structural and functional unit of neural system
- Generation and conduction of nerve impulse

The study was planned in the months of October and November, 2019, when the teachers of both the schools have finished a few portions of Unit 5: Human Physiology including Chapter 21, that is 'Neural Control and Coordination' for the summative assessment. The dates for the study were fixed with the help of subject teachers in the free periods by taking prior permission from the higher authorities of both schools. The drawings and graphical representations of students, collected from both schools before and after instruction, were analysed and categorised based on five levels of drawings criteria developed by Köse, (2008):

Level 1: No drawing and graphs
Level 2: Incorrect and non-representational drawings and graphs
Level 3: Drawings and graphs with misconceptions
Level 3a: Partially correct drawing and graphs
Level 3b: Partially incorrect drawing and graphs
Level 4: Correct and comprehensive annotated drawings and graphs

Tools used

Computer animations and graphics interchange formats showing annotated drawings and graphical representations of neural conduction developed by Youtube tutorial 'Teacher's Pet and Designmate' that was used for the instructional purpose (Figure 2). Open-ended interview was also conducted to diagnose the cause of misconceptions of the students.

Collection of the data

The concerned schools were visited for data collection and to administer the test.

Pre-instruction Phase

In this phase, students were asked to come prepared with the chapter 'Human Physiology' which had already been taught by their subject teachers and bring a plain paper and drawing items. On the other day, they were asked to draw detailed diagrams of myelinated and unmyelinated neuron, impulse conduction through axon relating it with voltage-time graph. Time assigned to complete the task was 30 minutes.

Instruction Phase

On the second day, students were asked to come to the computer lab of the school. A five minutes video showing computer animations on the structure of neuron, difference between myelinated and unmyelinated neurons, saltatory conduction, generation of action potential along the axon, voltage-time graph of oscilloscope, etc., was shown to the students twice. Each event in the video was described properly to the students relating it with the textbook content. Students were asked to carefully observe each and every event of the process and asked to clarify their doubts whenever they faced difficulty in understanding any concept.

Post-instruction Phase

In this phase, students were asked to again draw the diagrams and graphs of neural conduction by analysing the information that was provided in computer animation video. Time assigned was the same as before. At the same time, the drawings and graphs that they had drawn before the instruction were distributed to them. After finishing the task, they were asked to relate and compare their drawings and graphs drawn before and after instruction.

Data Analysis

The results were analysed by using percentage distribution. The calculation of frequency and percentage and preparation of graphs were done using Ms Excel, 2007 version.

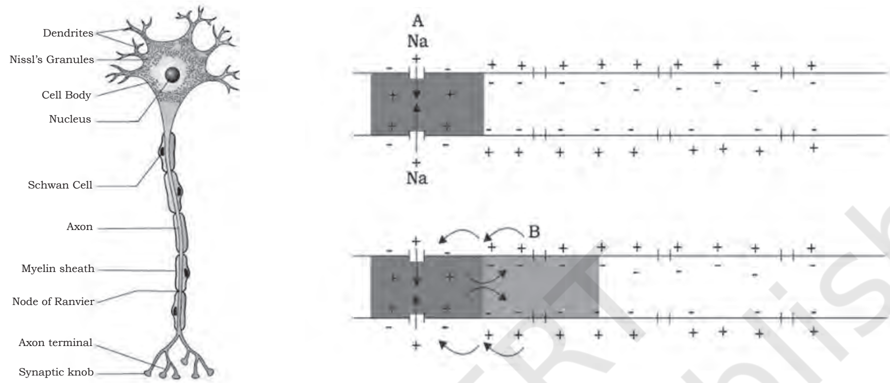

Fig. 1: Diagrams given in Class XI Biology NCERT textbook

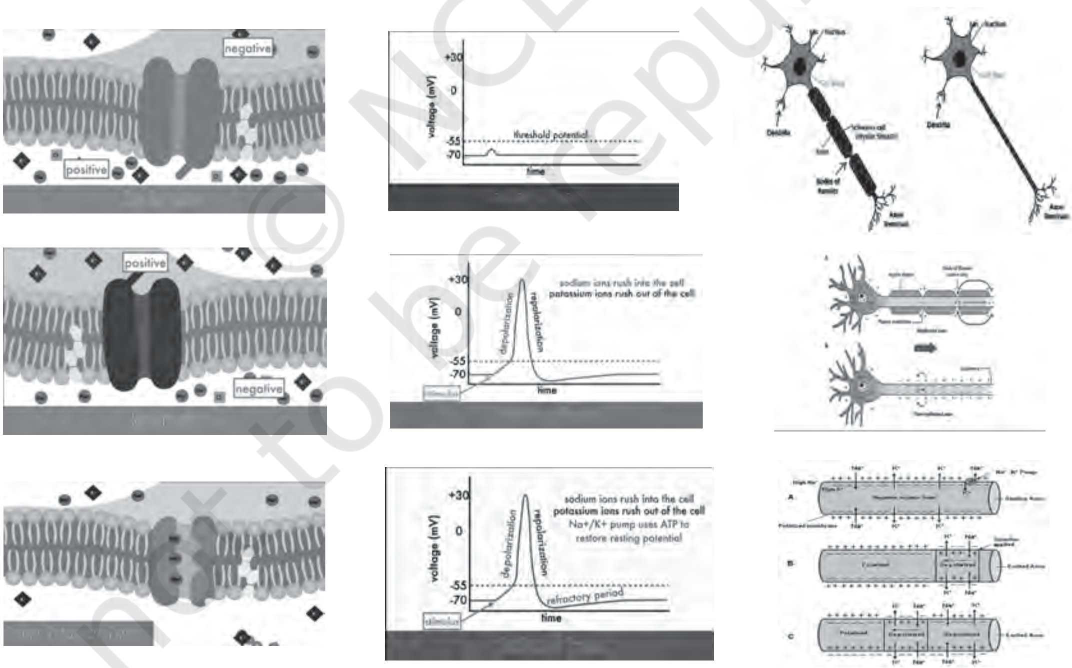

Fig. 2: A series of stills from the computer animations and graphics interchange formats showing annotated drawings and graphical representations used during study

Source: https://www.youtube.com/watch?v=FEHNIELPb0s (Teacher' Pet)
https://www.youtube.com/watch?v=1aSknHTnsYk (Designmate)

Results

The overall results of the pre-instructional study revealed that majority of the students, approximately 68 per cent (more than half) of both schools were having problem in the conceptual understanding of the basic concepts of neural conduction. This percentage was reduced by 13 per cent after instruction. About one-seventh of the students had not drawn any diagrams and graphs prior to the instruction. However, after instruction the percentage of students who had not attempted to make any drawing became negligible. About 13 per cent students had drawn incorrect drawings and graphs before instruction, this percentage decreased to only 4 per cent after instruction. Nearly 55 per cent students were having misconceptions previously, which got reduced to 51 per cent after instruction. The partially correct drawings and graphs were more than partially incorrect drawings before instruction. But the results were reversed after instruction. Only 19 per cent students of both schools had drawn correct and comprehensive annotated drawings and graphs during pre-instructional phase, while the percentage got increased to 42 per cent during post-instructional phase (Figure 3, Plate 1–4). The students of DMS were found to have more misconceptions in comparison to JNV students both at pre-instructional (60 per cent) and post-instructional level (58 per cent) (Figure 6). The most commonly drawn diagrams and frequent misconceptions of students of both schools that were observed in their drawings are listed in Table 1–2. We observed that the students of JNV were having more clear understanding about the neural conduction (pre-instruction: 28 per cent and post-instruction: 53 per cent) in comparison to students of DMS (Figure 4–6, Plate 1–4). There were no significant differences found in the results based on gender. The results of the open-ended interview of students revealed that the lack of ability to draw correct and comprehensive diagrams was due to:

- Lack of interest of learners towards Biology
- Lack of observational and creative skills
- Lack of actual application of drawings and graphs in real classroom situations
- Use of textbook drawings and lab charts for teaching
- Poor monitoring and assessment of students' drawings
- Lack of proper use of available audio-visual aids present in the school
- Lack of ICT-integrated instruction
- Traditional approach of teaching
- Unavailability of skilled teachers

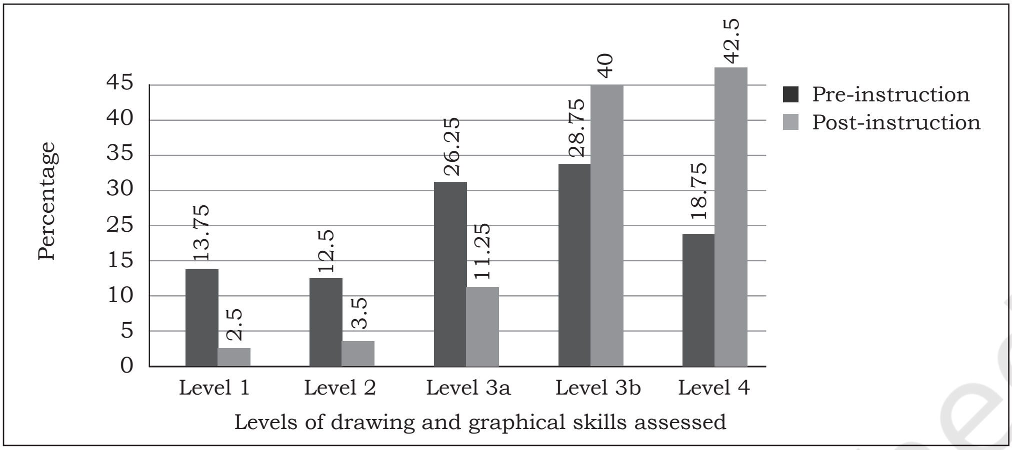

Fig. 3: Overall results of students responses of both schools

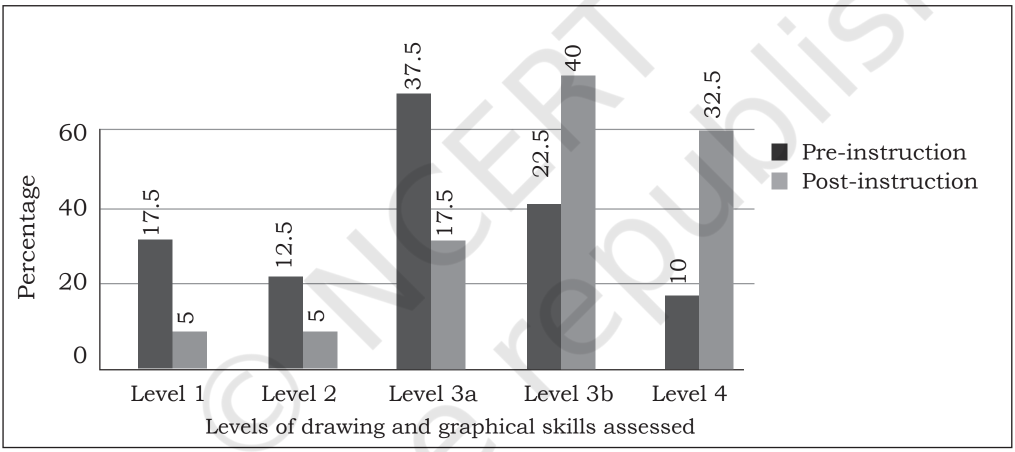

Fig. 4: Comparison between the responses of DMS students (before and after instruction)

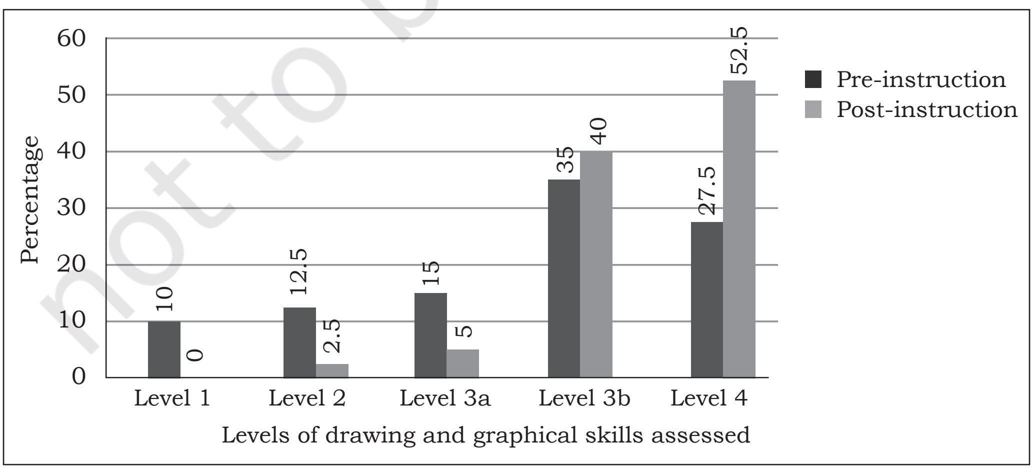

Fig. 5: Comparison between the responses of JNV students (before and after instruction)

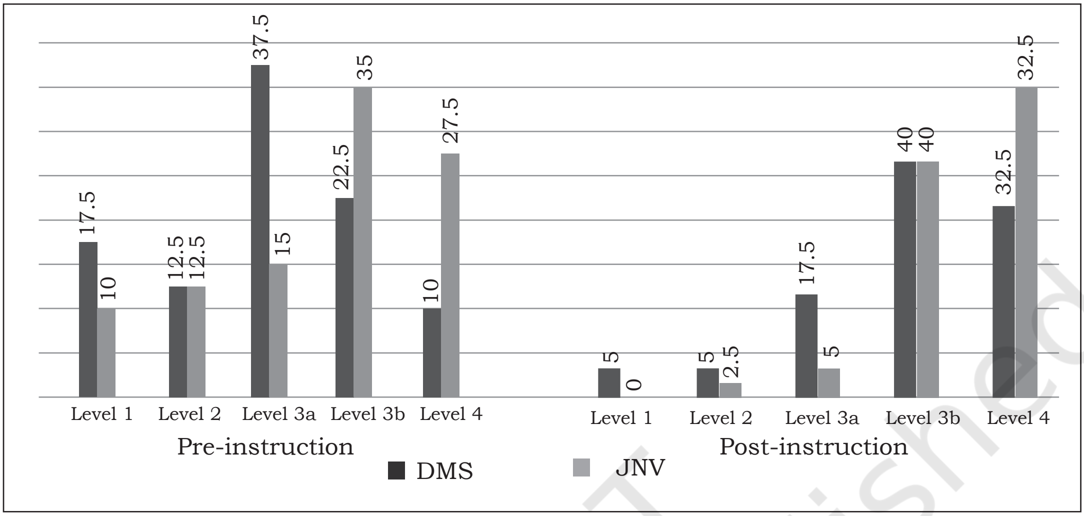

Fig. 6: Comparison between the pre-instruction and post-instructional results of DMS and JNV

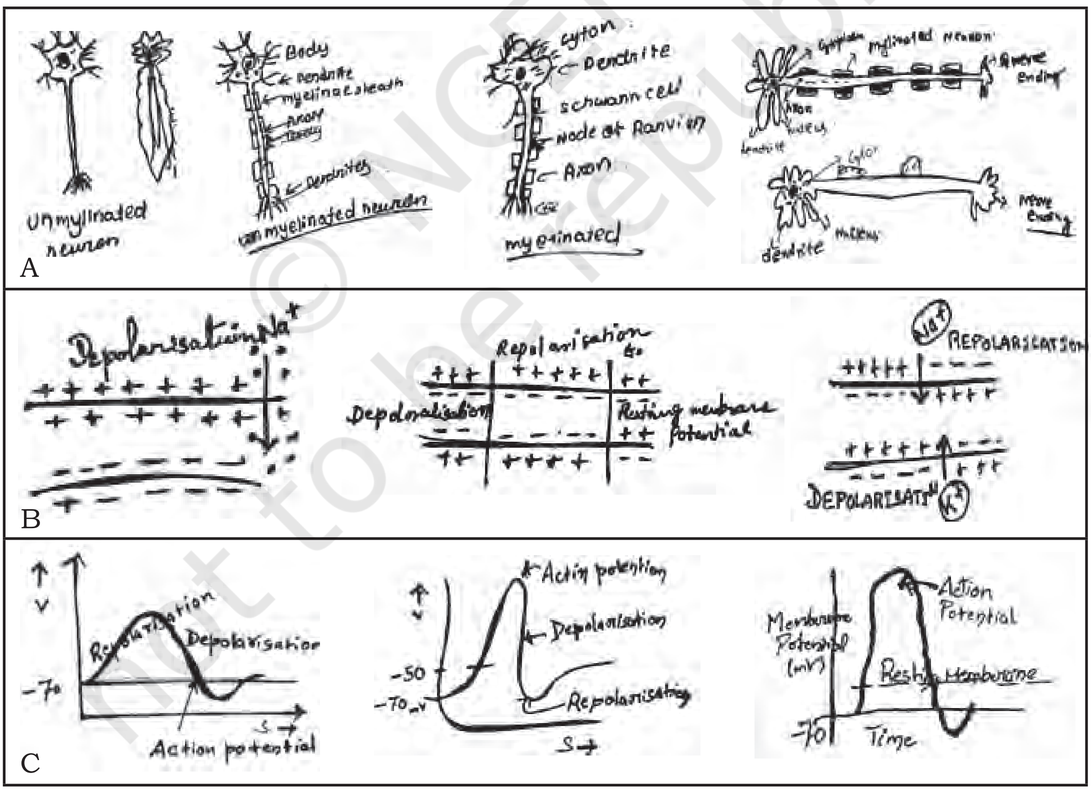

Plate 1: Example of Level 2— Incorrect and non-representational drawings and graphs drawn by students. A. Unmyelinated and Myelinated Neurons B. Diagram of impulse conduction through axon C. Voltage-time graph of action potential

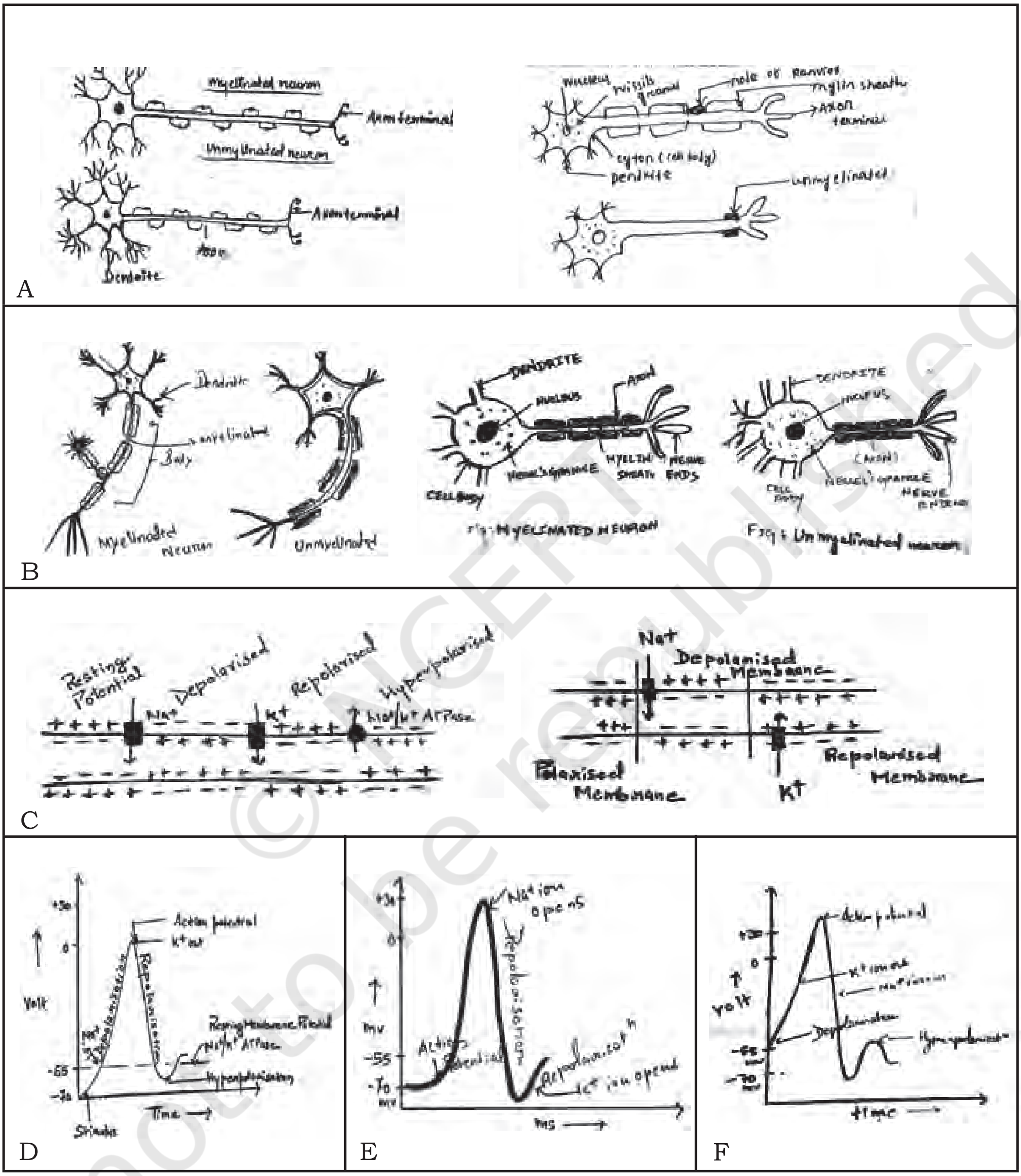

Plate 2: Example of Level 3a and 3b— Drawings and graphs with misconceptions drawn by students. A—B: Unmyelinated and Myelinated Neurons. C: Diagram of impulse conduction through axon. D—F: Voltage-time graph of action potential

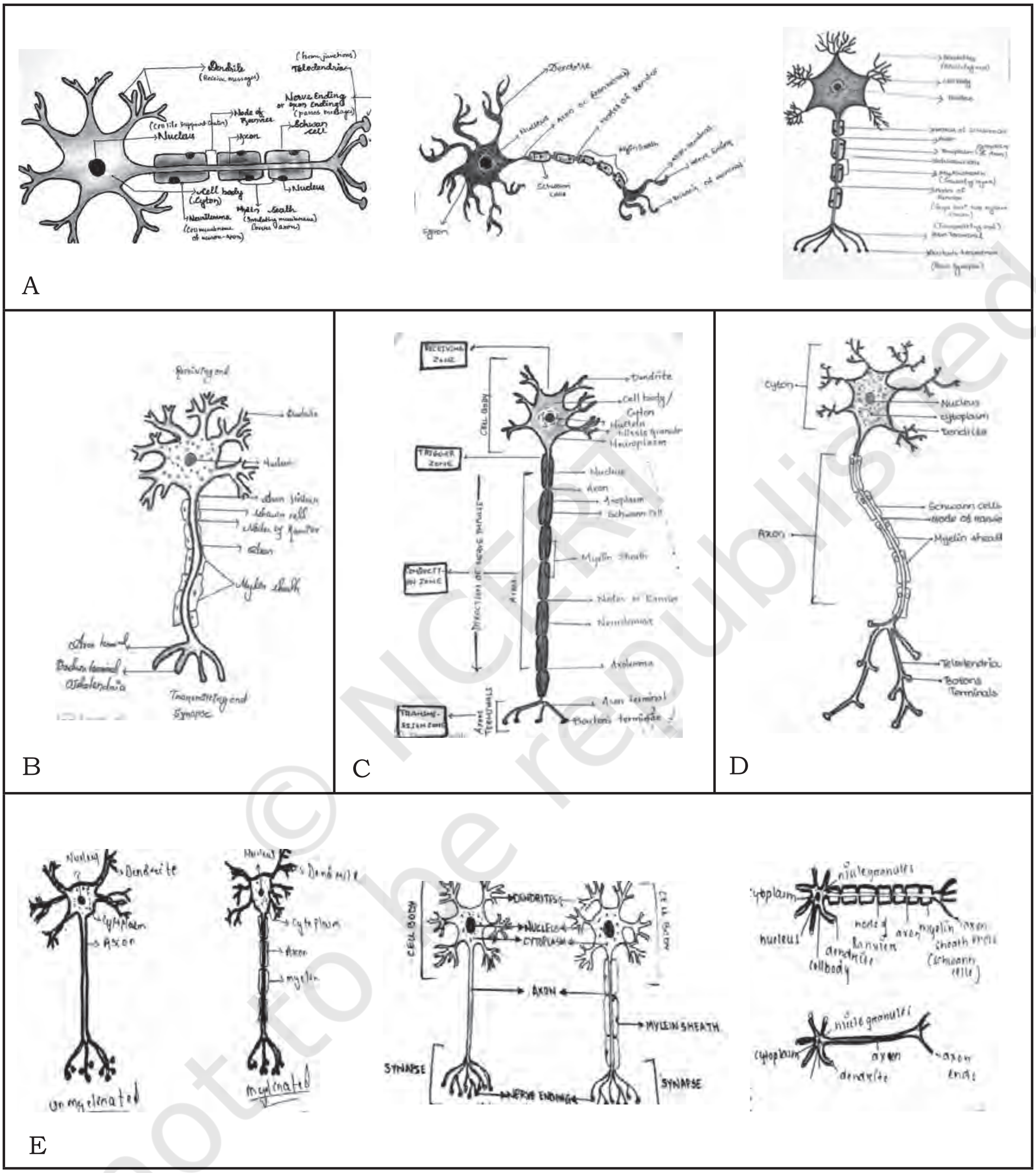

Plate 3: *Example of Level 4—Correct and comprehensive annotated drawings drawn by the students. A—D: Myelinated Neuron. E: Unmyelinated and Myelinated Neurons*

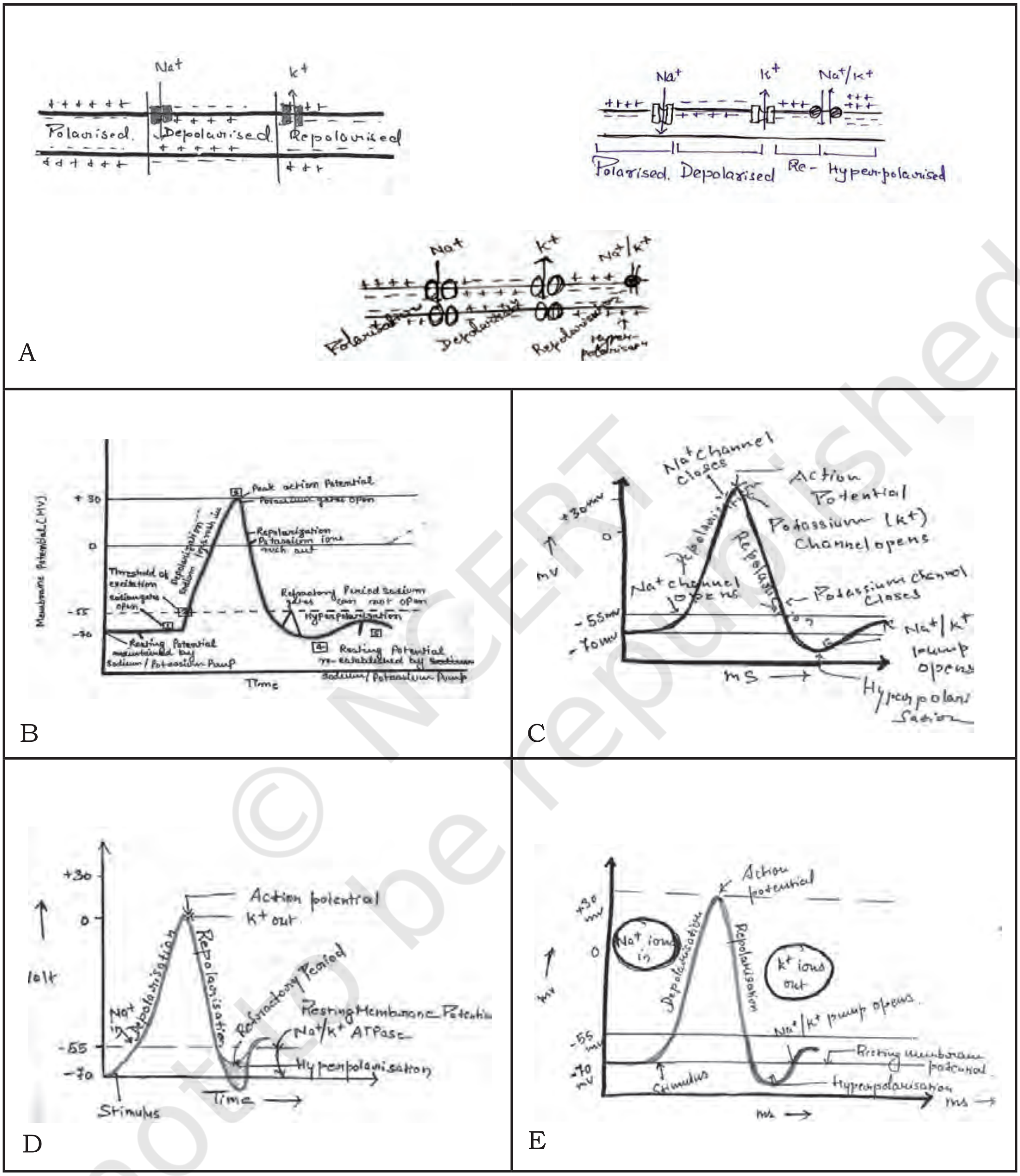

Plate 4: Example of Level 4—Correct and comprehensive annotated graphs drawn by the students. A: Diagram of impulse conduction through axon. B—E: Voltage-time graph of action potential

Table 1
The Most Frequent Components of Neural Conduction Drawn by Students

S.No.	Elements	n	%
1.	Cell body (soma)	69	86
2.	Axon	56	70
3.	Dendrites	51	64
4.	Axon terminals	37	46
5.	Synaptic knobs	29	36
6.	Axon hillock	23	29
7.	Nissl's granules	17	21
8.	Cell organelles in soma	15	19
9.	Schwann cell forming myelin sheath	13	16
10.	Nodes of Ranvier	11	14
11.	Impulse conduction through axon	10	13
12.	Membrane potential difference across different phases of impulse conduction	8	10
13.	Membrane proteins— ion channels	6	8
14.	Different phases of nerve impulse along with voltage time graph	4	5

Table 2
Analysis of Students' Misconceptions about Neural Conduction

	Misconceptions	Pre-instruction		Post-instruction	
		n	%	n	%
1.	Nissle granules are form of ribosomes in the cell body of neuron	33	41	17	21
2.	Schwann cells are found in unmyelinated neuron	29	36	11	14
3.	Saltatory conduction occurs in unmyelinated neuron	24	30	13	16
4.	The action potential generation is faster in unmyelinated neuron than in myelinated neuron	42	53	9	11
5.	Action potential occurs when membrane potential of a specific neuron continuously rises and falls	35	44	3	4
6.	The electrical potential difference between outside and inside of a nerve axon remains uniform throughout the neural conduction	17	21	4	5
7.	The depolarisation of nerve membrane takes place through influx of K^+ ions	8	10	5	6
8.	During repolarisation phase there is rapid influx of K^+ ions	13	16	2	3
9.	In repolarisation phase, the outside of axon will become positive and in hyperpolarisation phase, the outside becomes negative	11	14	6	8
10.	Na^+-K^+ ATPases are responsible for action potential generation	1	1	0	0

Discussion

The current trends in science education focus on giving more emphasis to process rather than content (Eurydice, 2012; Schwartz et al., 2012; Bybee, 2014; Duschl and Bybee, 2014; Osborne, 2014) in order to make science easily accessible to the learners. Unfortunately in practical context, these trends are not followed in real classroom situations. We explored in our study that approximately 68 per cent (more than half) of students from both schools face difficulties in understanding the basic concepts. Although, this was the result of a single pilot study, but findings are almost same everywhere. Drawings in Biology represent one's cognitive thinking which forms a part of the scientific process (Wasserman, 2013). Katz, P. (2017) described that drawing along with descriptive writing provide clarity and can make learning accessible. Students who draw providing proper annotation with text acquire greater knowledge than those who draw the same drawing without any description. Asking questions, developing and using models, engaging in arguments, and constructing and communicating explanations are the key strategies of effective learning (National Research Council, 2012). The ability to draw, label and annotate biological specimens is one of the important skills in Biology. Hattie (2003) mentioned that teachers contribute 30 per cent of variance in the academic achievement of the students. The reasons for incorrect drawings and graphs along with misconceptions may be attributed to unclear board diagrams drawn by the teachers and lack of appropriate instructions. Most of the teachers in the schools only follow textbook diagrams for teaching (Figure 1). Several times, the textbook diagrams are not updated according to recent trends, so the teachers must use supplementary references of drawings along with the text. The teachers spend least time on monitoring students' drawing skills and are not aware of how to improve or properly assess the students' drawing. The other reasons are well stated in the results of open-ended interview above. The results of multipurpose urban school clearly revealed that majority of the students have several misconceptions in their drawings on the topic of physiology (Table 2). The reasons included the unavailability of teachers, no coverage of the syllabus, lack of any projectors and white boards in the classrooms with non-engagement of computer labs during the periods, etc. On the other hand, inspite of remote rural location, the result of residential school students was better. Gogoi, Dutta and Soni (2016) in their study, revealed the similar results considering the intelligence level and academic achievement of JNV students. The students of JNV from the initial levels are engaged in creative activities and are trained to explore and observe more. This may be one of the reasons that they have more clear understanding about the concepts. Other reasons were attributed to the national entrance examinations which are conducted for the JNV students at elementary level to give learning opportunities to talented children. The remedial classes also help the students to clarify their doubts regarding what was taught in the class. The substantial use of audio-visual aids by the teachers helps students' involvement in projects. Also, individual and specific attention was given to each student by the concerned teacher to speed up their learning by addressing their queries.

Conclusions

We explored that the use of advance technologies to develop drawing and graphical skills improves the pace of learning among the students. Our conclusions suggest that teaching in Biology should shift from theoretical approach to the visual cognitive understanding of the concepts. The results of both multipurpose and residential school showed positive results after integrating computer animations during instruction. However, the result of residential rural school was better considering the previous knowledge of the students, intelligence level, regular advance pedagogic practices used by the teachers, infrastructural facilities, etc. Therefore, the students were aware of many concepts and had fewer misconceptions. The findings of this investigation may help the school teachers and curriculum makers to develop suitable methods of teaching and innovative instructional designs for learners to promote conceptual understanding of various topics in Biology.

References

Aggarwal, D.P. 2001. *Modern Methods of Teaching Biology*. Sarup and Sons Publishers. India, New Delhi.

Andersson, J., R. Löfgren, and L.A.E. Tibell. 2019. What's in the body? Children's annotated drawings. *Journal of Biological Education*. Vol. 54, No. 299. pp. 1–15. doi: 10.1080/00219266.2019.1569082.

Angra, A., and S.M. Gardner. 2017. Reflecting on Graphs: Attributes of Graph Choice and Construction Practices in Biology. *CBE- Life Sci Educ*. Vol. 16, No. 53. pp. 1–15.

Aydin, S. 2012. Establishment for misconceptions that science teacher candidates have about geometric optics. *The Online Journal of New Horizons in Education*. Vol. 2, No. 3. pp. 7–15.

Ayres, P., and F. Paas. 2007. Making Instructional Animations More Effective: A Cognitive Load Approach. *Applied Cognitive Psychology*. Vol. 21, No. 6. pp. 695–700.

Bungum, B. 2008. Images of Physics: An Explorative Study of the Changing Character of Visual Images in Norwegian Physics Textbooks. *Nordic Studies in Science Education*. Vol. 4, No. 2. pp. 132–141.

Bybee, R.W. 2014. NGSS and the Next Generation of Science Teachers. *Journal of Science Teacher Education*. Vol. 25, No. 2. pp. 211–221. doi:10.1007/s10972-014-9381-4.

Carvalho, G.S., R. Silva, N. Lima, E. Coquet and P. Clément. 2004. Portuguese Primary School Children's Conceptions about Digestion: Identification of Learning Obstacles. *International Journal of Science Education*. Vol. 26, No. 9. pp. 1111–1130. doi:10.1080 /0950069042000177235.

Chase, Z. 2014. The Toughest Class in Nursing School is the First One. *All Things Considered. National Public Radio.*

Colon-Berlingeri, M., and P.A. Burrowes. 2011. Teaching Biology Through Statistics: Application of Statistical Methods in Genetics and Zoology Courses. *CBE-Life Sciences Education*. Vol. 10, No. 3. pp. 259–267.

Cook, D.A., A.J. Levinson, S. Garside, D.M. Dupras, P.J. Erwin and V.M. Montori. 2008. Internet-based Learning in the Health Professions: A Meta-analysis. *JAMA (The Journal of the American Medical Association)*. Vol. 300, No. 10. pp. 1181–1196.

Cook, D.A. 2009. The Failure of e-learning Research to Inform Educational Practice, and What we can do About it. *Med Teach*. Vol. 31, No. 2. pp. 158–162.

Dempster, E., and M. Stears. 2014. An Analysis of Children's Drawings of What They Think is inside Their Bodies: A South African Regional Study. *Journal of Biological Education*. Vol. 48, No. 2. pp. 71–79. doi:10.1080/00219266.2013.837401.

Dempsey, B.C., and , B.J. Betz. 2001. Biological Drawing: A Scientific Tool for Learning. *The American Biology Teacher*. Vol. 63, No. 4. pp. 271–276.

Dimopoulos, K., V. Koulaidis, and S. Sklaveniti. 2003. Towards an Analysis of Visual Images in School Science Textbooks and Press Articles about Science and Technology. *Research in Science Education*. Vol. 33, No. 2. pp. 189–216.

Djanettea, B., and S. Fouadb. 2014. Determination of University Students' Misconceptions About Light Using Concept Maps. *Procedia— Social and Behavioural Sciences*. Vol. 152. pp. 582–589.

Duschl, R.A., and R.W. Bybee. 2014. Planning and carrying out investigations: an entry to learning and to teacher professional development around NGSS science and engineering practices. *International Journal of STEM Education*. Vol. 1, No. 1. p. 12. doi:10.1186/s40594-014-0012-6.

Eurydice. 2012. *Developing Key Competencies at School in Europe: Challenges and Opportunities for Policy*. Publication office of the European Union. Vol. 12, No. 11. pp. 1–72.

Evagorou, M., S. Erduran, and T. Mäntylä. 2015. The role of visual representations in scientific practices: from conceptual understanding and knowledge generation to 'seeing' how science works. *International Journal of STEM Education*. Vol. 2, No. 11. pp. 1–13. doi. 10.1186/s40594-015-0024.

Georghiades, P. 2004. Making pupils' conceptions of electricity more durable by means of situated metacognition. *International Journal of Science Education*. Vol. 26, No. 1. pp. 85–99.

Gilbert, J.K., M. Reiner, and M. Nakhleh. 2008. *Visualisation: Theory and Practice in Science Education*. The Netherlands: Springer. 978-1-4020-5266-8.

Gilbert, J.K. 2010. *The Role of Visual Representations in the Learning and Teaching of Science: An Introduction*. pp. 1–19.

Gogoi, N., J. Dutta, and J.C. Soni. 2016. A comparative study on academic achievement and intelligence of Class X students of Jawahar Navodaya Vidyalaya and Kendriya Vidyalaya in Lakhimpur District, Assam. *International Journal of Development Research*. Vol. 6, No. 3. pp. 7191–7198.

Gookin, J.L., D. McWhorter, S. Vaden, and L. Posner. 2010. Outcome assessment of a computer-animated model for learning about the regulation of glomerular filtration rate. *Advances in Physiology Education*. Vol. 34, No. 2. pp. 97–105.

Guy, R. 2011. Increasing Student Engagement in Physiology— The Use of Simple Spinal Reflex Animations. *Proceeding of the Australian Physiological Society*. Vol. 42. pp. 41–46.

———. 2012. Overcoming Misconceptions in Neurophysiology Learning: An Approach using Color-coded Animations. *Advances in Physiology Education*. Vol. 36. pp. 226–228. doi:10.1152/advan.00047.2012.

Hattie, J. 2003. Teachers Make a Difference, What is the research evidence? *Australian Council for Educational Research*. pp. 1–17.

Kararo. M., and M. McCartney. 2019. Annotated Primary Scientific Literature: A Pedagogical Tool for Undergraduate Courses. *PLOS Biology*. Vol. 17, No. 1. pp. 1–9. https://doi.org/10.1371/journal.pbio.3000103.

Katz, C., Z. Barnetz, and I. Hershkowitz. 2014. The Effect of Drawing on Children's Experiences of Investigations following Alleged Child Abuse. *Child Abuse and Neglect*. Vol. 38, No. 5. pp. 858–67.

Katz, P. 2017. *Drawing for Science Education: An International Perspective*. University of Maryland, USA. pp. 1–8.

Kose, S. 2008. Diagnosing Student Misconceptions: Using Drawings as a Research Method. *World Applied Sciences Journal*. Vol. 3, No. 2. pp. 283–293.

Lehrer, R., and L. Schauble. 2012. Seeding evolutionary thinking by engaging children in modeling its foundations. *Science Education*. Vol. 96, No. 4. pp. 701–724. doi:10.1002/sce.20475.

Montagna, E., A.M.S. Azevedo, C. Romano, and R. Ranvaud. 2010. What is transmitted in "synaptic transmission"? *Advance Physical Education*. Vol. 34, No. 2. pp. 115–116.

Michael, J. 2002. Misconceptions— what students think they know. *Advance Physical Education*. Vol. 26. pp. 5–6.

National Research Council. 2012. A Framework for K-12 Science Education. National Academies Press. Washington DC.

Nielsen, B. L. 2014. Students' annotated drawings as a mediating artefact in science teachers' professional development. *Nordic Studies in Science Education*. Vol. 10, No. 2. pp. 162–175.

Ormanci, Ü., and F. S. Ören. 2011. An analysis of pre-service teachers' drawings about the digestive system in terms of their gender, grade levels, and opinions about the method and subject. *International Journal of Biology Education*. Vol. 1, No. 1. pp. 1–22.

Osborne, J. 2014. Teaching scientific practices: meeting the challenge of change. *Journal of Science Teacher Education*. Vol. 25, No. 2. pp. 177–196. doi:10.1007/s10972-014-9384-1.

Óskarsdóttir, G., B. Stougaard, A. Fleischer, E. Jeronen, F. Lützen, and R. Kråkenes. 2011. Children's Ideas about the Human body— A Nordic Case Study. *Nordic Studies in Science Education*. Vol. 7, No. 2. pp. 179–189. doi:10.5617/nordina.240.

Pelaez, N. J. 2005. Prevalence of blood circulation misconceptions among prospective elementary teachers. *Advances in Physiology Education*. Vol. 29, No. 3. pp. 172–181. doi:10.1152/advan.00022.2004.

Picone, C., J. Rhode, L. Hyatt, and T. Parshall. 2007. Assessing gains in undergraduate students' abilities to analyse graphical data. *Teaching Issues and Experiments in Ecology*. Vol. 5, No. 1. pp. 1–54.

Schwartz, R.S., N.G. Lederman, and F. Abd-el-Khalick. 2012. A series of misrepresentations:a response to Allchin's whole approach to assessing nature of science understandings. *Science Education*. Vol. 96, No. 4. pp. 685–692. doi:10.1002/sce.21013.

Silverthorn, D.U. 2002. Uncovering misconceptions about the resting membrane potential. *Advances in Physiology Education*. Vol. 26, No. 1–4. pp. 69–7. doi:10.1152/advan.00012.2002

Slutsky, D.J. 2014. The Effective Use of Graphs. *Journal of Wrist Surgery*. Vol. 3, No. 2. pp. 67–68. doi: 10.1055/s-0034-1375704.

Sturges, D., and Maurer, T. 2013. Allied health students' perceptions of class difficulty: the case of undergraduate human anatomy and physiology. *Internet J Allied Health Sci Practical*. Vol. 11, No. 4. pp. 1–10.

Tairab, H.H., and Al-Naqbi, A.K. 2004. How do secondary school science students interpret and construct scientific graphs? *Journal of Biological Education*. Vol. 38, No. 3. pp. 127–132.

Quillin, K., and Thomas, S. 2015. Drawing-to-Learn: A Framework for Using Drawings to Promote Model-Based Reasoning in Biology. *CBE-Life Sciences Education*. Vol. 14, No. 1. pp. 1–16.

Reiss, M.J., S.D. Tunnicliffe, A.M. Andersen, A. Bartoszeck, G.S., Carvalho, S.Y. Chen, and W. V. Rooy. 2002. An International Study of Young Peoples' Drawings of What Is inside Themselves. *Journal of Biological Education*. Vol. 36, No. 2. pp. 58–64. doi:10.1080/00219266.2002.9655802.

Rowlands, M. 2004. What Do Children Think Happens to the Food They Eat? *Journal of Biological Education*. Vol. 38, No. 4. pp 167–171. doi:10.1080/00219266.2004.9655936.

Ruiz, J.G., D.A. Cook, and A.J. Levinson. 2009. Computer animations in medical education: a critical literature review. *Medical Education*. Vol. 43, No. 9. pp. 838–846. doi: 10.1111/j.13652923.2009.03429.x.

Van Merrienboer, J.J. and J. Sweller. 2010. Cognitive load theory in health professional education: design principles and strategies. *Medical Education*. Vol. 44, No. 1. pp. 85–93.

Wainers, H. 2013. *Medical Illumination: Using Evidence, Visualization and Statistical Thinking to Improve Healthcare*. Oxford, UK: Oxford University Press.

Wasserman. M.L. 2013. Drawing as Thinking: An Enquiry into the Act of Drawing as Embodied Extension of Mind. *Disseration Thesis*. University of KwaZulu-Natal.

Wu, H.K. and P. Shah. 2004. Exploring visuospatial thinking in chemistry learning. *Science Education*. Vol. 88, No. 3. pp. 465–492. doi:10.1002/sce.10126.