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Identification of Misconceptions in the Teaching of Biology: A Pedagogical Cycle of Recognition, Reduction and Removal

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Abstract

To date research into how young people acquire accurate higher-order scientific knowledge, and gain an understanding of abstract and challenging concepts in science, has occupied much of the science education literature across countries and across continents. In previous studies, we identified that biology teaching that involves the diagnosis, reduction and elimination of misconceptions can be one effective pedagogic approach, particularly if positioned within a "good enough" model of pedagogic practice[1]. In this study, we investigate the use of one diagnostic testing approach to the identification of misconceptions in the teaching of respiration and photosynthesis in a small sample of secondary school students (n=139) and pre-service teachers (n=43) in the Republic of Ireland. Photosynthesis and respiration were chosen as they are prevalent biology topics that students find conceptually challenging. The study used test items to elicit the extent of misconceptions among this cohort – a paper-and-pencil test for students and a survey instrument for pre-service teachers. The findings show unacceptably high level of misconceptions among all pre-service teachers and students and suggest that diagnostic tests of this type can be a useful entry point to a pedagogical cycle for the recognition, reduction and removal of misconceptions. The findings have wider implications than this small scale study and are primarily directed toward new understandings in relation to more effective models of biology teaching and teacher education.

Key words: Teaching of biology; Misconceptions; Students; Pre-service teachers; Diagnostic tests; Pedagogic practice; Good enough model; Respiration and photosynthesis; Teacher education

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INTRODUCTION

To date research into how young people acquire accurate higher-order scientific knowledge, and gain an understanding of abstract and challenging concepts through various supports and scaffolds, has occupied much of the science education literature across countries and across continents (Bradley, Croker, Zimmerman, Gill, & Romig, 2013). Studies in educational psychology have measured the effect size of a variety of instructional strategies along a continuum, starting with effective instruction and specific task-oriented feedback opportunities (Hattie, 2009; Hattie, 2012; Hattie & Yates, 2014). It appears that within such a clinical model of "best practice" an effective science teacher will merely require technical competence to accurately diagnose the "problem", select and apply appropriate expert knowledge from a bank of available research and display the data indicating successful outcomes. However, as argued by Connell (Connell, 2009), and other sociologists and philosophers of education (Ball, 2003; Biesta, 2010)

[1] Details with Editor.

such a clinical "best practice" model fails to take the ever changing dynamic of practice and the socio-cultural context into account and, for the most part, fails in practice to provide reform outcomes demanded by policymakers.

Biology misconceptions have been recognized as a major factor affecting students' understanding of science at secondary school level with many misconceptions carried onwards to university studies (Coll & Treagust, 2003). Studies show that both in-career teachers and pre-service teachers have misconceptions in certain biology (Burgoon, Heddle, & Duran, 2011). Therefore, in order to improve science education, it is imperative that all teachers find new and innovative ways to identify and amend misconceptions that they may have (Burgoon et al., 2011). In previous studies, we identified that effective science teaching requires the diagnosis and reduction of misconceptions in the teaching of conceptually challenging biology topics, such as, respiration and photosynthesis[2]. In these studies we argued that effective biology teaching is more appropriately positioned within a "good enough" model of practice operating as a continuous pedagogical cycle of recognition, reduction and removal of misconceptions rather than the application of a singular definitive technique[3].

In this article, we first define a misconception and identify how misconceptions are formed and their implications for the teaching of biology. Second, we highlight the prevalent misconceptions identified in the literature in relation to photosynthesis and respiration and the multiple ways identified to identify and eliminate these in teacher education. Third, we outline the research methodology used in this small scale biology study and the pre-piloting of two diagnostic tests, for recognition of misconceptions in photosynthesis and respiration held by pre-service teachers and secondary school students (age 16 years to 19 years) in one Initial Teacher Education (ITE) program at the university. Fourth, we present the tests items and findings from the study. Finally, we discuss the wider implications within an international literature as a search for more effective models of biology teaching and teacher education into the future.

1. LITERATURE REVIEW

In this study, we define the term misconception as "any conceptual idea that differs from the commonly accepted scientific consensus" (Garnett & Treagust, 1990). Misconceptions for students often arise from communication issues with different science teachers, peer group interactions in social media and elsewhere and often uncritical use of textbooks (Abimbola & Baba, 1996; Dikmenli & Cardak, 2004; Donovan & Bransford, 2005; Kendeou & Van den Broek, 2008). Misconceptions in the literature, such as, textbooks, have been shown as a strong source of misconceptions for students and their teachers, identified by a range of different problems, such as, oversimplifications, over generalizations, lack of clarity about central concepts, and incorrect diagrams and analogies (Güler & Yağbsan, 2008; Hershey, 2004). Leaving misconceptions unchallenged seriously undermines efforts to improve the scientific literacy of the general citizenry and the acquisition of accurate knowledge for those who proactively pursue science programs, either in science education or as a study of the discipline (Gooding & Metz., 2011; Keeley, Eberle, & Farrin, 2005).

This study mostly viewed learning as taking place within a social constructivist paradigm, encouraging active learning and providing students with opportunities and specific feedback to build their knowledge base [3]. However, the researchers were aware of the limitations of this model of teaching and learning, contested as an over-socialized model that often downplays the important role played by access to theoretical and disciplinary knowledge in the acquisition of scientific knowledge (Young & Muller, 2011). Whichever is the case, the biology teacher cannot underestimate the effect of prior-learning, experience and ideas on the learning capacity of the student. It has been shown that meaningful and deep learning occurs when new information is effectively related to existing prior-knowledge (Hattie, 2009; Hattie, 2012). Thus, studies show that using examples, analogies, explanations and imagery can all considerably improve the probability for meaningful and deep learning to occur (Morrison, Ross, Kalman, & Kemp, eds., 2011).

It is nowadays recognized that contemporary pedagogical practices in the Republic of Ireland offer few opportunities to develop students' thinking and argumentation competences [1-3]. In order for higher-order capacities to develop, authentic change is required in the ways science lessons are structured and oriented, and the ways all teachers, from pre-service teachers through to in-career teachers, are supported and challenged in teacher education[4]. It is clear that students need to engage more actively with learning processes, with cognitive and metacognitive development and motivational scaffolds and supports (Bradley et al., 2013; Driver, Newton, & Osborne, 2000; Scott, Asoko, & Driver, 1997) demonstrate the importance of students' prior conceptions in the successful acquisition of accurate scientific knowledge (Johnson & Lawson, 1998).

Studies in the literature, suggest that in order to overcome misconceptions, students need a well-developed critical awareness in relation to scientific misconceptions so that they can continually identify and

[2] Idib.
[3] Idib.
[4] Idib.

upgrade their conceptual mapping of scientific ideas, using good analogies and other conceptual approaches, to acquire accurate scientific concepts (Clement & Brown, 2004; Kern & Crippen, 2008; Smith, Disessa, & Roschelle, 1994). Using a broad-based conceptual toolkit of pedagogic practices have reduced many scientific misconceptions for students and, in some instances, removed them completely (Karamustafaog˘lu, Sevim, Mustafaog˘lu, & Cepni, 2003).

2. MISCONCEPTIONS IN PHOTOSYNTHESIS AND RESPIRATION

Photosynthesis and respiration were chosen as they are prevalent topics that secondary school students find conceptually challenging. The word 'respiration' is commonly used in everyday language. Students are often taught that lungs are part of the respiratory system, which may contribute to the development of this misconception in the first instance (Deshmukh & Deshmukh, 2007). Terms like "respiratory system", "respiratory organ", in which the term "respiratory" needs to be replaced with "breathing", are commonly used in text-books and by teachers. Another strongly held misconception, held by both students and teachers alike, is that "respiration only occurs in animals and not plants". This is partly due to some authors defining terms like respiration almost exclusively for animals (Songer & Mintzes, 1994).

Another commonly held misconception is that photosynthesis takes place during the day, whereas respiration takes place only at night. Certainly, there is more emphasis given to the process of photosynthesis and the fact that it takes place during daylight in comparison to when respiration occurs in plants (Wandersee, Mintzes, & Novak, 1994). Cellular respiration is a continuous process in all organisms. The emphasis on the process of photosynthesis must have resulted in the misconception that cellular respiration occurs only at night in plants. Research has revealed that a number of prevalent misconceptions about photosynthesis, such as: plants get food from the soi1, water and minerals taken in from the soil are sources of the plant's "food", photosynthesis is the respiration of plants and photosynthesis takes place during the day whereas respiration takes place only at night [2].

3. MISCONCEPTIONS AND TEACHER EDUCATION

Studies suggest that all teachers need to find appropriate ways to recognize and confront their own misconceptions, and become supported in this regard in teacher education programs, before they can effectively assist students (Burgoon et al., 2011). Therefore, in order for teachers to implement conceptual change strategies with their students, it appears they themselves need to possess a high standard of disciplinary content knowledge and a high degree of awareness of each individual student's misconceptions (Gomez-Zwiep, 2008). Once their students' misconceptions are recognized and diagnosed, teachers need to provide multiple opportunities in the classroom for students to confront misconceptions for their reduction and possible elimination through reconstructing new scientifically accurate conceptual knowledge (National Research Council, 1997; Modell, Michael, & Wenderoth, 2005).

It can be difficult for science teachers to implement effective active learning strategies in this regard without themselves engaging in a multiplicity of educative opportunities, such as, dialogue, reflective practice, argumentation, meaningful guidance, and access to research literature (Keys & Bryan, 2001). Science teacher higher education programs need to interrupt the cycle of misconceptions and proactively assist pre-service teachers develop effective practices to identify, reduce and improve the probability of eliminating misconceptions (Asay & Orgill, 2010; Driver et al., 2000). Deliberative models of curriculum innovation, mentoring and support for teachers using a number of scaffolds and supports, such as, school-university partnerships, have been shown to build ethical trust and ownership of the change process[5]. In this study, we explore the use of diagnostic tests, by pre-service teachers and students respectively, to identify misconceptions in photosynthesis and respiration and as an entry point to a pedagogical cycle of recognition, reduction and removal at the level of the classroom.

4. RESEARCH METHODOLOGY

The key question driving this study was to explore the effectiveness of two diagnostic tests, for pre-service teachers and students respectively, to reveal the extent of misconceptions in photosynthesis and respiration, the types of misconceptions found and to explore their suitability as an entry point to a pedagogical cycle in this regard. A total of one hundred and eighty two respondents took part in this small scale study of biology teaching and teacher education (n=182)—one hundred and thirty nine secondary school students (n=139) and forty three pre-service biology teachers (n=43).

The identification instrument for students was a paper and pencil diagnostic test of nineteen multiple choice questions, both traditional and pictorial, addressing the key research question. Each multiple choice question consisted of five possible answers a, b, c, d & e. As per (Sheehan, 2010) and (Griffard & Wandersee, 2001) each question consisted of one correct answer, one misconception identified in the literature, along with two

[5] Idib.

distracter answers and an option to choose if they didn't know the answer. This test instrument was designed, tested and the results analysed using a statistical package known as Predictive Analytics Software (PASW). There were two sections in the identification instrument. Section A was related to the personal profile of each student. Section B assessed the number of misconceptions present among secondary school students. A number of draft versions of the identification instruments were reviewed by experts in the disciplinary field. Modifications noted by the experts were reviewed and adjusted accordingly. A pilot-test was also carried out with six secondary school students who completed the test instrument before it was distributed to schools to ensure the questions were readable and readily understood.

A separate survey, Section C, was developed as a diagnostic test for pre-service biology teachers in the ITE program at the university. These students were in their third year of a four year biology teacher education degree. It consisted of six statements where the pre-service teachers were asked to choose a response, from a scale of five possible responses: strongly agree, agree, unsure, disagree and strongly disagree. This section was included to firstly examine whether pre-service science teachers had the ability to define a misconception and, secondly to identify whether they were already analysing the existence of misconceptions amongst their students and thirdly, to ensure they were familiar with possible or common misconceptions in the research literature. The results from both tests were presented as percentages.

5. FINDINGS

5.1 Findings From Students

The percentage of students that chose to answer Section B of the identification instrument is illustrated in Table 1. It is evident that some misconceptions were more prevalent than others. The question the secondary school students found most difficult to answer was Question 17. This question was in relation to gaseous exchange. Gaseous exchange occurs in all living plants, animals and micro-organisms but the mechanism of the gaseous exchange can differ. It takes place at a respiratory surface that is a boundary between the interior of the organism and the external environment. Bearing this in mind, students were asked to circle the correct answer. 28.26% of the students chose option E for this question stating they did not know the answer to the question. Another related question that held a dominant misconception amongst students was Question 11: "Gaseous exchange takes place…" with 39.13% of students holding the misconception that "Gaseous exchange in plants takes place only through the stomata in the leaves". The correct response being gaseous exchange occurs in the stomata, stems and general surface of the roots.

Question 1, which stated "Photosynthesis is": Appeared to be a predominant misconception amongst the students. 36.96% of students believed that the compounds were produced from organic molecules instead of inorganic molecules. Question 6 also showed a high level of misconception amongst the students. This question was to determine if students were able to make an accurate distinction between the absorption and reflection of light. 37.68% of the students examined, held the misconception that "plants absorb all colors of white light except green; green light is reflected by plants and is not used in photosynthesis". Only 4.35% of the students answered this question correctly.

The results obtained from Question 8: "Like humans, plants grow with time but what causes an increase in the size of plants?" emphasized that students believe that plants get their food from the soil. 42.75% of the students from the study held the misconception that plants got their food from the soil. Question 14 tested students' understanding of plant respiration. Answers chosen indicated that students have difficulty understanding the continuity of plant respiration. Only 17% of the students answered correctly that plants respire continuously during the day and night. In this regard, the findings indicate a high level of misconceptions among students.

Table 1
The Percentage of Upper Secondary Students That Held the Following Misconceptions Identified in the Identification Instrument and the Percentage of Students That Answered the Questions Correctly

No.	Answers chosen by the candidates containing the misconceptions identified in the literature	% of students that held misconception	% of students with correct answer
1	Photosynthesis is the production of organic compounds from organic molecules using light energy harnessed by chlorophyll (Wood-Robinson, 1991).	36.96	13.04
2	Sunlight is the only source of light that can be trapped by the plant (Marmaroti & Galanopoulou, 2006).	24.64	39.86
3	During photosynthesis light energy and the heat of the sun is necessary for the plant to make food (Marmaroti and Galanopoulou 2006).	29.71	30.43
4	Anaerobic respiration does not require oxygen to make carbon dioxide and ATP and will not occur in the presence of oxygen (Seymour & Longden, 1991).	26.09	41.30
5	Plants produce their own food by trapping energy from the sun during photosynthesis and are therefore called heterotrophic organisms (Martlew & Connolly, 1996).	26.09	49.28

To be continued

Continued

No.	Answers chosen by the candidates containing the misconceptions identified in the literature	% of students that held misconception	% of students with correct answer
6	Plants absorb all colours of white light except green; green light is reflected by plants and is not used in photosynthesis (Hershey, 2004).	37.68	4.35
7	The Calvin cycle occurs during the night only; it is light independent but still depends on some of the products of the light stage (Haslam & Treagust, 1987).	25.36	13.77
8	Plants increase in size as they are provided with a support structure, food and minerals from the soil (Barman et al., 2003).	42.75	4.35
9	Water and carbon dioxide taken into plants are not changed. They are unchanged to support two separate life processes (Roth & Anderson, 1987).	7.25	37.68
10	Breathing and respiration are synonymous as they are both involved in the mechanical and the bio-chemical processes (Bishop et al., 1986).	24.64	23.19
11	Gaseous exchange in plants takes place only through the stomata in the leaves (Maskill & Cachapuz, 1989).	39.13	34.06
12	In the process of respiration, plants demonstrate this balancing technique by taking in carbon dioxide from their environment and in turn, producing the required quantity of oxygen to balance this (Haslam & Treagust, 1987).	22.46	34.78
13	Oxygen and water are released from the plant using a cellular transport process called osmosis (Prokop & Fančovičová, 2006).	10.87	27.54
14	Aerobic respiration occurs during the day and the night while anaerobic respiration in plants can only occur during the night (Haslam & Treagust, 1987)	25.36	17.00
15	With reference to energy in photosynthesis, energy is produced by the plant to help the plant grow stronger (Driver et al., 1994).	13.04	48.55
16	Food and nutrients are absorbed by the roots in the soil and travel to all parts of the plant (Roth & Anderson, 1987).	29.71	21.01
17	Plant respiration can be referred to as an inverse gaseous exchange compared with that of animal respiration (Canal, 1999).	28.6	55.07
18	Photosynthesis is a process by which light energy from the sun is combined with oxygen gas and water to form glucose and carbon dioxide. A green pigment called chlorophyll is needed as a catalyst for this process (Ekici et al., 2007).	16.67	37.68
19	Plants also obtain food from the soil through their roots (Bahar et al., 1999).	31.16	36.96

5.2 Findings From Pre-Service Teachers

Almost 90% of pre-service biology teachers agreed they were familiar with the term misconception. 75% of them believed that if they were aware of the students' misconceptions they could readily change them. However, less than 2% of the pre-service biology teachers said they researched the literature for knowledge of possible misconceptions in a particular topic. The majority of pre-service teachers in the study agreed they were familiar with the term misconception and believed that if they were aware of the students' misconceptions they could more readily begin the change process (Figure 1).

The questions pre-service teachers found most difficult to answer were Questions 6 and 17. These questions were in relation to chloroplast pigments and gaseous exchange. White light is composed of different wavelengths of light. Chloroplasts contain a range of pigments, including chlorophyll. Each of the chloroplast pigments absorbs a different colour of light. Bearing this in mind pre-service teachers had to choose the correct statement. In relation to Question 17, gaseous exchange occurs in all living plants, animals and micro-organisms but the mechanism of the gaseous exchange can differ. It takes place at a respiratory surface that is boundary between the interior of the organism and the external environment. Bearing this in mind students were asked to circle the correct answer. 13.95% of the pre-service teachers chose option E for both of these questions stating they did not know the answer to the question.

Questions answered the most accurately were Questions 2, 5, 18 and 19. Question 2 asked where plants get light, carbon dioxide and water. 76.74% of the pre-service teachers answered this question correctly. In relation to question 5, 83.72% of the pre-service teachers answered this question correctly. This question required pre-service teachers to circle the correct statement in relation to a diagram of describing different energy levels. Question 18 was in relation to the process of photosynthesis; what substances are taken in and given out to the environment. 86.05% of the pre-service teachers answered the question correctly. Question 19 was in relation to energy; 74.42% of the pre-service teachers answered this question correctly.

Question 6 about chloroplast pigments was badly answered. Only 2.33% of the pre-service teachers answered the question correctly. Question 1 was a pictorial question which was answered rather poorly with 23.26% providing the correct answer to the question. A number of common misconceptions held by this cohort of pre-service teachers were identified from the findings of the study. The most dominant misconception was found to be in Question 9 where 51.16% of pre-service teachers held the misconception that carbon dioxide and water are changed to support two life processes. Question 17 also held a very prevalent misconception among pre-service teachers with 37.21% of the belief that gaseous plant respiration is an inverse gaseous exchange compared with that of animals. A high misconception was portrayed in Question 11 where 34.88% chose the option stating that gaseous exchange only occurred through the stomata in the leaves.

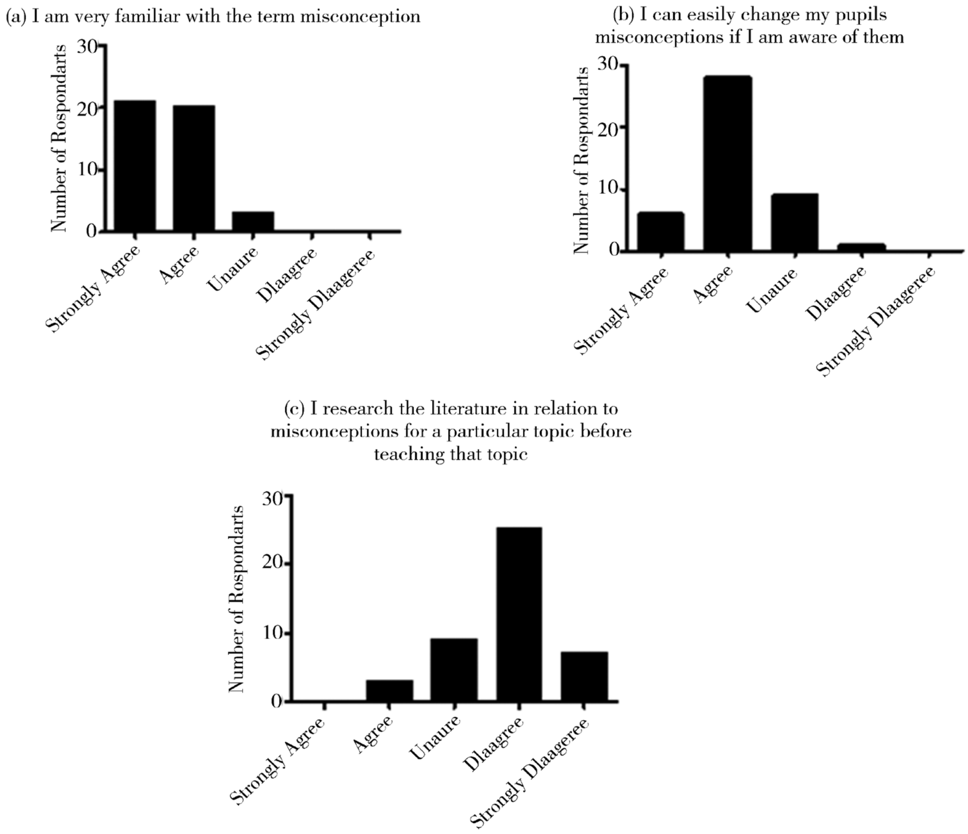

Figure 1
Pre-Service Teacher's Responses to Survey

In summary, the analysis of responses given by the secondary school students and third year undergraduate pre-service science teachers to the two diagnostic instruments indicated that Biology misconceptions, in the topics of photosynthesis and respiration, were widespread and persistent across both groups of respondents. The main findings from this analysis are as follows:

Overall, a high percentage of misconceptions were evident amongst secondary school students and pre-service science teachers in the study.

Pre-service teachers were not in the habit of drawing from research literature or using peer-support conversations in relation to interrogating their own misconceptions or researching effective pedagogic practices in relation to well-known and common misconceptions in the topic they were teaching.

The test instruments used in this study were relatively easily designed, administered and analysed and could well be adapted to become part of a broad-based conceptual toolkit and an important entry point for these pre-service teachers to a pedagogical cycle for the recognition, reduction and removal of misconceptions, for themselves and for their students.

DISCUSSION

It has been shown that the identification of misconceptions in biology is essential for scientific misconceptions to be addressed and for the acquisition of accurate scientific knowledge to be developed and advanced (Bell, 2001; Hodgson & Pyle, 2010; Mayer, 2002; Ross, Tronson, & Raymond, 2006). Science teacher education in the Republic of Ireland has traditionally focused on subject matter content knowledge in the sciences in preference to elicit discussion in relation to achieving an effective learner centered classroom. The findings from this small scale study of pre-service teachers and students show unacceptably high levels of misconceptions in these conceptually challenging biology topics, photosynthesis and respiration. According to (Diakidoy & Iordanou, 2003) in order to implement conceptual change, it is imperative for the teacher to first recognize the extent of the problem. It is evident that pre-service teachers in this study were underestimating the critical nature of the "problem" of students' misconceptions, also observed by (Burgoon et al., 2011). More worryingly, pre-service teachers in the study appeared to be less interested in accessing and using research literature to identify common misconceptions related to specific teaching topics. Also, these pre-service teachers were not engaging in forms of peer-supported dialogue in this regard. As a result, the pre-service teachers in this study were largely unaware of access to a multiplicity of effective pedagogic practices that have been already used to successfully overcome scientific misconceptions in the teaching of biology[6].

Overall, the findings from this study showed that the two diagnostic test instruments were relatively easy to design and administer and were able to reveal the levels and types of misconceptions. They could be adapted and become an entry point into a pedagogical cycle, of recognition, reduction and removal, for misconceptions are to be effectively diagnosed and eliminated in the acquisition of accurate scientific knowledge. Explicitly presenting the misconceptions identified by these diagnostic tests to pre-service teachers, and students, may help scaffold and challenge their thinking and reasoning capacities and assist in the generation of multiple innovative practices needed to potentially overcome them (Angell, Ryder, & Scott, 2005). This will become part of a future research study in this regard. However, this development will clearly need to become supported by multiple models of teacher development, such as, learning in networks, collaborative action research, reflective practices, to achieve lasting change in teachers' specialist knowledge base and pedagogic practices (Luft, Roehrig, & Patterson, 2003; Penso, Shoman, & Shiloah, 2001; Van Driel, Beijaard, & Verloop, 2001).

CONCLUSION

Effective and evidence-informed pedagogic practices are clearly needed by all teachers, and students, to identify, overcome and eliminate misconceptions in the acquisition of accurate scientific knowledge. One way of improving the quality of teachers in this regard can be achieved by targeting pre-service teachers, ensuring that they have capacity to continually interrogate their misconceptions, while working alongside peers and teacher educators to recognize and reduce, if not completely remove, biology misconceptions.

The implications from this small scale study have wider international significance and pose challenges to all teacher educators and policymakers. They suggest that a "best practice" clinical model, merely requiring technical competence, is nowadays largely outdated and newer models of a 'good enough' practice are needed for biology teaching and teacher education that understands the elimination of scientific misconceptions as a pedagogical cycle of improvement rather than a singular technique or training event. Further research study is called for in this regard into the future.

[6] Idib.

REFERENCES

Abimbola, I. O., & Baba, S. (1996). Misconceptions & alternative conceptions in science textbooks: The role of teachers as filters. *The American Biology Teacher*, *58*(1), 14-19.

Angell, C., Ryder, J., & Scott, P. (2005). Becoming an expert teacher: Novice physics teachers' development of conceptual and pedagogical knowledge. *Studies in Science Education.*

Asay, L. D., & Orgill, M. K. (2010). Analysis of essential features of inquiry found in articles published in The Science Teacher "1998–2007". *Journal of Science Teacher Education, 21*(1), 57-79.

Ball, S. J. (2003). The teacher's soul and the terrors of performativity. *Journal of Education Policy, 18*(2), 215-228.

Bell, E. (2001). The future of education in the molecular life sciences. *Nature Reviews Molecular Cell Biology*, *2*(3), 221–225.

Biesta, G. J. J. (2010). Good education in an age of measurement. *Ethics, Politics, Democracy.* London: Paradigm.

Bradley, J., Croker, S., Zimmerman, C., Gill, D., & Romig, C. (2013). Gaming science: The "Gamification" of scientific thinking. *Frontiers in Psychology*, *4*(607), 1-16.

Burgoon, J. N., Heddle, M. L. & Duran, E. (2011). Re-examining the similarities between teacher and student conceptions about physical science. *Journal of Science Teacher Education, 21*(7), 859-872.

Clement, J., & Brown, D. (2004). Overcoming misconceptions via analogical reasoning: Abstract transfer versus explanatory model construction. *Instructional Science, 18*(4), 237-261.

Coll, R. K., & Treagust, D. F. (2003). Investigation of secondary school, undergraduate, and graduate learners' mental models of ionic bonding. *Journal of Research in Science Teaching, 40*(5), 464-486.

Connell, R. (2009). Good teachers on dangerous ground: Toward a new view of teacher quality and professionalism. *Critical Studies in Education, 50*(3), 213-229.

Deshmukh, N. D., & Deshmukh. V. M. (2007). A study of students' misconceptions in biology at the secondary school level: Proceedings of *epiSTEME-2. An International Conference to Review Research on Science, Technology and Mathematics Education,* (pp.137-141). Delhi, India: Macmillan India Ltd.

Diakidoy, I. A., & Iordanou, K. (2003). Pre-service teachers and teachers' conceptions of energy and their ability to predict pupils' level of understanding. *European Journal of Psychology of Education, 23*(1), 357–36.

Dikmenli, M., & Cardak, O. (2004). A study on misconceptions in the 9th grade high school biology textbooks. *Eurasian Journal of Education Research, 17*(1), 130-141.

Donovan, M., & Bransford, J. (2005). *How students learn science in the classroom*. Washington, DC: National Academies Press.

Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education, 84*(3), 287-312.

Garnett, P. J., & Treagust, D. F. (1990). Implications of research on students' understanding of electrochemistry for improving Science curricula and classroom practice. *International Journal of Science Education, 12*(2), 147-156.

Gooding, J., & Metz., B. (2011). From misconceptions to conceptual change. *The Science Teacher, 78*(4), 34-37.

Griffard, P. B., & Wandersee, J. H. (2001). The two-tier instrument on Photosynthesis: What does it diagnose?. *International Journal of Science Education, 23*(10), 1039-1052.

Güler, D., & Yağbsan., R. (2008). The description of problems relating to analogies used in science and technology textbooks. *Journal of the Faculty of Education, 9*(16), 105-122.

Hershey, D. R. (2004). *Avoid misconceptions when teaching about plants*. Website http://www.actionbioscience.org/education/hershey. html [accessed 23 July 2013].

Hattie, J. (2009). *Visible learning: A synthesis of over 800 meta-analyses relating to achievement.* Abingdon, Oxon: Taylor & Francis.

Hattie, J. (2012). Visible learning for teachers. *Maximizing impact on learning.* London and New York: Routledge.

Hattie, J., & Yates, G. (2014). *Visible learning and the science of how we learn*. London: Routledge.

Hodgson, C., & Pyle, K. (2010). *A Literature review of Assessment for Learning in science*. National Foundation for Educational Research.

Keeley, P., Eberle, F., & Farrin, L. (2005). *Uncovering student ideas in science: 25 formative assessment probes.* Arlington, VA: National Science Teachers Association Press.

Johnson, A. M., & Lawson, E. A. (1998). What are the relative effects of reasoning ability and prior knowledge on Biology achievement in expository and inquiry classes? *Journal of Research in Science Teaching, 35*(1), 89-103.

Karamustafaog˘lu, S., Sevim, S., Mustafaog˘lu, O., & Cepni, S. (2003). Analysis Turkish high-school chemistry examination questions according to bloom's taxonomy. *Chem Educ Res Pract, 4*(1), 25–30.

Keys, C. W., & Bryan, L. A. (2001). Co-constructing inquiry-based Science with teachers: Essential research for lasting reform. *Journal of Research in Science Teaching, 38*(6), 631-645.

Kendeou, P., & Van den Broek, P. (2008). Cognitive processes in comprehension of science texts: The role of co-activation in confronting misconceptions. *Applied Cognitive Psychology, 22*(3), 335-351.

Kern, C., & Crippen, K. J. (2008). Mapping for conceptual change. *Science Teacher, 75*(6), 32-38.

Morrison, G. R., Ross, S. M., Kalman, H. K., & Kemp. J. E., (Eds.). (2011). *Designing effective instruction,* (6th ed.). Hoboken: John Wiley and Sons.

Scott, P.H., Asoko, A. H., & Driver, R. H. (1997). *Teaching for conceptual change: A review of srategies children's learning in Science*. Research Group University of Leeds, UK.

Smith, J. P. I., Disessa, A. A., & Roschelle, J. (1994). Misconceptions reconceived: A constructivist analysis of knowledge in transition. *The Journal of the Learning Sciences, 3*(2), 115-163.

Gomez-Zwiep, S. (2008). Elementary teachers' understanding of students' science misconceptions: Implications for practice and teacher education. *Journal of Science Teacher Education , 19*(5), 437-454.

Luft, J. A., Roehrig, G. H., & Patterson, N. C. (2003). Contrasting landscape: A comparison of the impact of different induction programs on beginning secondary science teachers' practices, beliefs, and experiences. *Journal of Research in Science Teaching, 40*(1), 77 - 97.

Modell, H., Michael, J., & Wenderoth, M. P. (2005). Helping the learner to learn: The role of uncovering misconceptions. *The American Biology Teacher, 67*(1), 20-26.

Mayer, R. E. (2002). Rote versus meaningful learning. *Theory Practice*, *41*(1), 226–232.

National Research Council. (1997). *Science teaching reconsidered: A handbook*. Washington, DC: National Academy Press.

Sheehan, M. (2010). *Identification of difficult topics in the teaching and learning of chemistry in Irish schools and the development of an intervention programme to target some of these difficulties* (Master's thesis). Published by University of Limerick.

Ross, P., Tronson, D., & Raymond, J. R. (2006). Modelling photosynthesis to increase conceptual understanding. *Journal of Biological Education, 40*(2), 84-88.

Songer, C. J., & Mintzes, J. J. (1994). Understanding cellular respiration: An analysis of conceptual change in college biology. *Journal of Research in Science Teach*ing, *31*(1), 621-637.

Penso, S., Shoman, E., & Shiloah, N. (2001). First steps in novice teachers' activity. *Teacher Development, 5*(3), 323 - 338.

Van Driel, J. H., Beijaard, D., & Verloop, N. (2001). Professional development and reform in science education: The role of teachers' practical knowledge. *Journal of Research in Science Teaching, 38*(2), 137-158.

Wandersee, J. H., Mintzes, J. J., & Novak, J. D. (1994). Research on alternative conceptions in science. In D. L. Gabel (Ed.), *Handbook of research on science teaching and learning* (pp.177-210). New York: Macmillan.

Young, M. & Muller, J. (2011). Three educational scenarios for the future: Lessons from the sociology of knowledge. *European Journal of Education*, *45*(1), 11-27.