

ASERS

Journal of Research in Educational Sciences

Annually

Volume V

Issue 1(7), 2014

ISSN: 2068 – 8407

Journal DOI: <https://doi.org/10.14505/jres>

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ISSN 2068 – 8407

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Journal of Research in Educational Sciences

The Journal is designed to promote scholars' thought in the field of education with the clear mission to provide an interdisciplinary forum for discussion and debate about education's most vital issues. We intend to publish papers that contribute to the expanding boundaries of knowledge in education and focus on research, theory, current issues and applied practice in this area.

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The Editor in Chief would like to invite submissions for the **Volume VI, Issue 8, 2015** of the **Journal of Research in Educational Sciences** (JRES).

The primary aim of the Journal has been and remains the provision of a forum for the dissemination of a variety of international issues, empirical research and other matters of interest to researchers and practitioners in a diversity of subject areas linked to the broad theme of educational sciences.

The aims and scope of the Journal includes, but is not limited to; the following major topics as they relate to the Educational Sciences:

- Educational Psychology;
- Engagement and Community;
- Leadership in Education;
- School Improvement;
- Human Resources in Education;
- Education and Information Science;
- Global strategies in Higher Education;
- Learner's Needs in the 21st Century;
- The Role of Education in The Globalization World;
- Technology-Based Learning;
-Any other related topic.

All papers will first be considered by the Editors for general relevance, originality and significance. If accepted for review, papers will then be subject to double blind peer review.

Deadline for Submission:	25 th August 2015
Expected Publication Date:	November 2015
Web:	www.asers.eu/journals/jres/
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Understanding of Genetic Information and RNAi Therapeutic Application in Medical Faculty Students in Northeast Sri Lanka and the Implications for Genetics Education

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Abstract:

This study examines students' understanding of the normative connections between key concepts of genetics, and RNAi and underlying biological principles that are critical for an in-depth understanding of RNAi therapeutic application on Medical field. Using a structural questionnaire, we examine randomly selected Medical faculty students' understanding of genetic relationships at Faculty of Medicine and Allied Sciences, University of Rajarata, Sri Lanka. A total of 80 Medical faculty students participated in this study and completed written questionnaire on genetics and RNAi therapeutic application. Findings from this study were there is a strong positive response on basic genetics studies in this content, but when it considers knowledge on RNAi and new technology based on RNAi therapeutic application is poorly understood. Almost all the students had a good knowledge on DNA but not the relationship between gene and DNA. Specifically, students were requested to demonstrate an integrated understanding of the RNAi therapeutic application, almost 96% of them unable to give an example for it, and also some students struggled to explain it. Outcome of this study is preliminary in nature; the results provide cause for concern over the status of genetics education in Sri Lanka need to uplift.

Keywords: Genetics, genetics education, RNAi, therapeutic application

1. Introduction

Many people say that we must get ready to live in the digital age. These same people have the mistaken notion that every person can learn to live in this new age with a minimum of effort and understanding of genetics (Davis 1948; Duncan *et al.* 2009). Almost 100 years after coining of the terms “genetics” and “gene”, the field of genetics has expanded to cover many areas beyond merely the study of inheritance. A good understanding of genetics now requires knowledge about structure and function of the cell to understand genetic applications (Chattopadhyay 2005).

Genetics is one of the most difficult subjects in the biology curricula at the ordinary level and advance level (Longden 1982; Hallden 1988) and college and university levels (Brumby 1984; Kindfield 1994) even in Sri Lanka. Studies in other countries have shown that understanding of genetics and its various aspects is poor among students of various levels and among the population in general (Lewis *et al.* 2000; Wood-Robinson *et al.* 2000; Marbach-Ad 2001). Genetics education has become increasingly important with the advent of recombinant DNA technologies and the subsequent emergence and availability of genetically modified food and organisms (GMOs), and RNA interference (Tuschi 2002).

Implications of recent developments of the so-called “New Genetics” have been widely discussed in the scientific community and among the general public. Legal and ethical concerns focus on policy agenda: the appropriate use of genetic tests and population screening, the possibility of genetic discrimination, and the “destiny” of transgenic resources (Orcajo & Aznar 2005; Venville *et al.* 2005; Alozie *et al.* 2010). Research on the public understanding of genetics has shown that Mendelian concepts are not always understood, and lay ideas are used to explain heredity phenomena in different settings (Lewis & Kattmann 2004; Duncan & Reiser 2007).

RNA interference (RNAi) is a regulatory mechanism of most eukaryotic cells that uses small double stranded RNA (dsRNA) molecules to direct homology-dependent control of gene activity (Almeida & Allshire 2005). Several rapidly developing RNA interference (RNAi) methodologies hold the promise to selectively inhibit gene expression in mammals. RNAi is an innate cellular process activated when a double-stranded RNA (dsRNA) molecule of greater than 19 duplex nucleotides enters the cell, causing the degradation of not only the invading dsRNA molecule, but also single stranded (ssRNAs) RNAs of identical sequences, including endogenous mRNAs. As such, RNAi technology is currently being evaluated not only as an extremely powerful instrument for functional genomics analyses, but also as a potentially useful method to develop highly specific dsRNA based gene-silencing therapeutics.

To the best of my knowledge, almost no reports in Sri Lanka have examined students’ knowledge and understanding of biology topics related to genetics. In this study, although preliminary in nature, I begin to address this area of science education research, which has relevance for curriculum developers, textbook writers, and teachers to think and teach new technologies (Zohar & Nemet 2002; Dawson & Schibeci 2003).

Sri Lankan Educational System

The present educational system in Sri Lanka includes school and university levels. The school system extends from class I to class XII, which has four categories: primary (I–V), secondary (VI–X),

Tertiary (XI-XII), and finally higher education levels at the university. Although the secondary and tertiary is considered part of school education, it is taught mostly in Ordinary and Advance level which is similar to UK based system. In Sri Lanka, the topic of genetics is introduced either at the secondary level (classes IX–X) or at the tertiary level level (classes XI–XII).

2. Methodology of research

General Background of Research

This research was designed to collect knowledge on RNAi and its therapeutic applications ideas on inheritance of genetic disorders. The questionnaire which was administrated to the medical students had three parts: Student responses in the Gene section, Student responses in the RNAi section, and Student responses in the RNAi therapeutic application, and detail follows

Mapping student knowledge on genetic code

In Figure 1, represent that illustrates the biological relationships between DNA, RNA and Gene which will finally produce a protein. The sequence of a coding strand of DNA, read in the direction from 5' to 3', consists of nucleotide triplets (codons) corresponding to the amino acid sequence of a protein read from N-terminus to C-terminus. Sequencing of DNA and proteins makes it possible to compare corresponding nucleotide and amino acid sequences directly. There are 64 codons (each of 4 possible nucleotides can occupy each of the three positions of the codon, making $4^3 = 64$ possible trinucleotide sequences). Each of these codons has a specific meaning in protein synthesis: 61 codons represent amino acids; 3 codons cause the termination of protein synthesis. The breaking of the genetic code originally showed that genetic information is stored in the form of nucleotide triplets, but did not reveal how each codon specifies its corresponding amino acid. It shows that genes and chromosomes are contained in all cells, and it was made up with nucleotides. The representation also illustrates key biological distinctions in the processes of protein production. Furthermore, this biological representation serves as a starting point for our research into the ideas and connections among ideas that students hold about basic genetics.

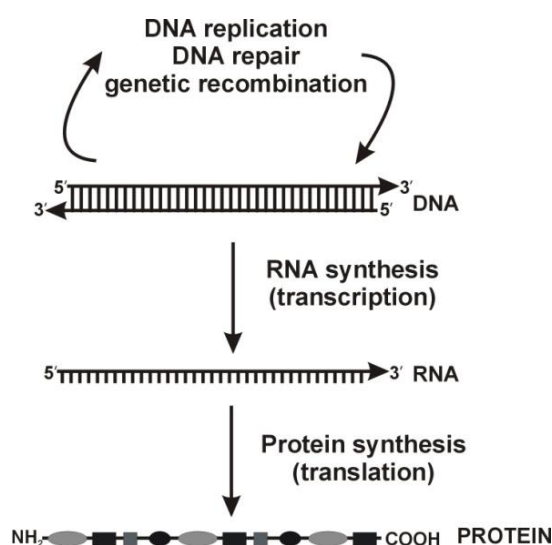


Figure 1 – Central Dogma

Students' ideas on some basic aspects related to RNAi

The main aim of this section is to show what students knew about the basic scientific concepts related to the RNAi: (a) before their first academic approach to genetics; and (b) after they had studied these basic notions in a traditional way (i.e., by teacher explanation and textbooks).

RNAi considered as double stranded RNA (dsRNA) caused potent and sequence specific silencing of homologous genes. Beyond this, the response to dsRNA had a number of nearly unbelievable properties. Silencing occurred not only in cells directly exposed to the dsRNA, but also spread throughout the organism and into its progeny. In this section, the study of RNAi has proceeded along two parallel tracks. The first is an effort to understand the biology of this response – its mechanism and its role in the organism. The second has been the desire to develop RNAi as an experimental possibly therapeutic tool which is used in this decade (Figure 2).

From the point of view of the logic of the discipline, and as a first approach to genetics, an elementary knowledge of the location of biological inheritance information in people, organisms in whose life cycle the diploid state is dominant. To understanding of the concepts of genetics following questions were asked (Figure 2):

- 'RNAi' stands for which of the following?
- Andrew Fire and Craig Mello won a Nobel Prize in 2006 for their work, begun in the late 1990s, on RNA interference. Which of the following organisms did they work on?
- The effectors of gene silencing are short double-stranded RNA molecules produced by the action of the enzyme dicer. Approximately what size are these molecules?
- There are hopes that RNAi will have a wide range of therapeutic applications. It may be possible to use microRNAs to silence oncogenes. Which of the following is caused by oncogenes?
- Why can transgenes activate RNAi (can circle more than one)

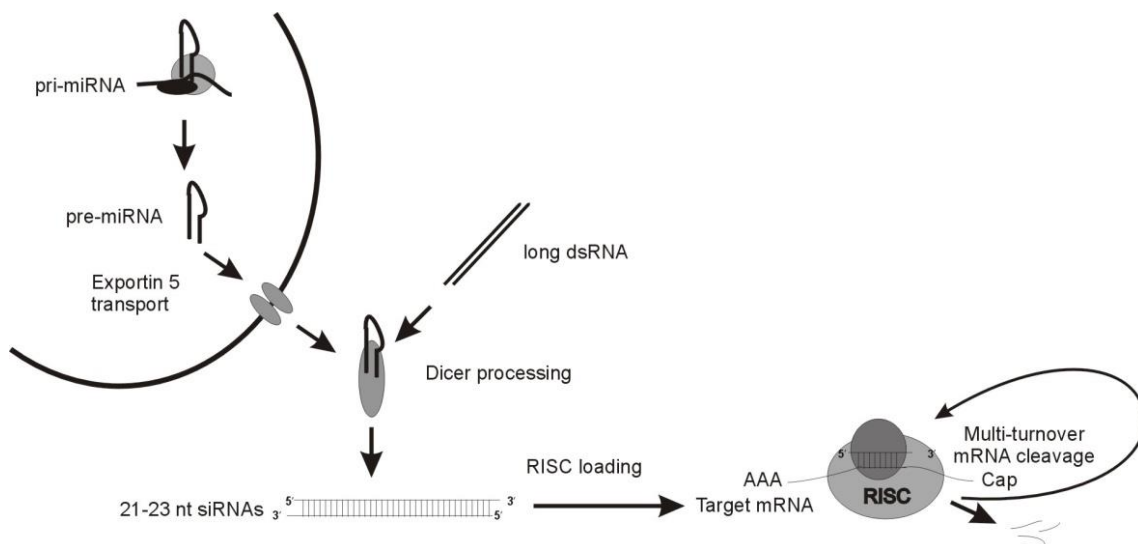


Figure 2 – Pathway and formation of RNAi

Student responses in the RNAi therapeutic application

Although the technology of RNAi and initial procedures involved in therapeutic in human application, the end-products and applications are different. In therapeutic RNAi, a cloned plasmid is created and stimulated so that it begins growing. (Just like reproductive cloning, this involves inserting the genetic material of a donor into target region so that the resulting is cure to the patient.). In this sectional study also wanted to know what students knew about how some RNAi therapy in real time. For this, questions asked them whether they know any examples with regard to RNAi therapeutic application:

- Patients who have a disease called X have over growth in muscle. Scientists know that X is inherited (caused by a gene). Therefore, the gene responsible for X does not contain correct information about;
- To cure the above symptoms RNAi therapy can be introduce, what is the main function of it;
- Give an example of an RNAi therapy which is used current treatment to cure any disease/s.

Educational researchers, on the other hand, have stressed student's "misunderstanding" of scientific concepts of genetics taught at school, such as genes, chromosome, DNA, and RNAi (Wood-Robinson, Lewis and Leach 2000). The findings showed that students do not have a good understanding of RNAi and do not make the link between related concepts of their own with respect to RNAi therapeutic application. Learning failure is seen either as a result of inadequate teaching of concepts or because the students are simultaneously exposed to a wide variety of concepts and processes at different levels of complexity. However, all these investigations were aimed at describing the failure of the teaching–learning process rather than at understanding what students actually

Sample selection

In this study it was examined knowledge and understanding of concepts related to basic genetics and RNAi application in therapeutic application among Rajarata Medical faculty students in Sri Lanka. This topic was judged to be extremely important for good conceptual understanding of genetics and to find out in detail knowledge on current trend in RNAi technology.

Instrument and procedure

Questionnaire Used

A written questionnaire, developed by our team as part of the "Learning in genetics with RNAi therapeutic application," The questionnaire has three parts: the "Gene" section; "RNAi" section; and the "RNAi application" section. It combines both fixed- and free answer–type questions. The questionnaire was used in the Sri Lanka for medical faculty students first time. Use of the questionnaire in this study was justified because it had been prepared by an experienced research group working in genetics education and already had been tested before the research part. In addition, the questionnaire was designed to assess conceptual understanding of topics also included in Sri Lankan university curriculum.

Research Context and Participants

In this study main objective is to highlight the genetic competencies in the university sector and therefore eighty university students took part in this study. Four batches were represented equally from, freshers, sophomores, juniors and seniors from Faculty of Medicine and Allied Sciences, University of Rajarata, Sri Lanka, which was located in Saliyapura, Anuradhapura. All were enrolled in medical education course. The study was conducted with a sample of 80 students (46 males and 34 females). The students in each batches learned about basic of genetics, and gene knockdown, and molecular genetics, except the fresher's. The faculty is a socially and economically diverse community in Northern Province of the country. The participating school was the only medical faculty in that province. The students had the biochemistry backgrounds and appeared in the selection examination (an examination conducted by the faculty for 2nd MBBS) after completing their 2-yr courses to qualify for the final examination conducted by the Faculty. They would have been expected to know the answers to the questions asked in the study questionnaire.

Administration of Questionnaire to the Medical Students

The questionnaires were administered at each of the respective batches at the Medical faculty, University of Rajarata within the class periods of 45 min with the help of the lecture in charge. Questionnaires were distributed to 20 students at each batch and students were selected randomly. Care was taken to avoid any exchange of information or ideas among students.

Data Analysis

To address the three research section questions, questions were compared informal reasoning displayed by individuals representing high and low genetics understanding. The validity of the translation was independently assessed by two observers competent in English language. Data was analyzed as a balanced Figure as percentage of application. Statistical analysis was done via transformed all the data using the basic statistical analysis package.

3. Results

Gene Section

A basic description of the gene section of the questionnaire is available in Table 1. In short, the questions examined knowledge and understanding of the genetics and its relationship. Emphasis was given to estimating students' awareness of the concept that "DNA and genetic information and its importance". For the first three questions of the study reported here, students were asked to identify a gene, and how it was made, as given below:

- Which analogy best describes what genes are like?
- What, if any, is the connection between DNA and genes?
- DNA and RNA are made of?

Student responses to these three questions are summarized in Table 1. Responses to each of the three questions were coded, and the frequency of different responses was noted. It was found that only 7.5% of the total number of students gave reasons for their responses to all of the questions; they responded explicitly but not always correctly. Mostly 3rd year students were the given correct answer on this section. Because examining student understanding was an important objective of the study, a second analysis was conducted on the 80 questionnaires in which students gave explicit views on which

analog describe the gene. It was 61.3% which is slightly above average. Basic question which was in this section was DNA and RNA how they made up, I was expecting 100%, but the outcome of the research is 91.3%, which made me to think how to teach the basics to students.

Student responses to questions in this section pointed toward two problematic concepts-the relationship among gene and DNA and surprisingly what is gene. Using the two concepts, students' "understanding" can be described as falling within one of the following categories:

- understands the basic idea of DNA and RNA is satisfactory
- understands the basic idea about gene but does not distinguish between relationship with DNA
- poor understanding it gives confused or incorrect responses. So, none of the students gave the correct answer for all three questions on this section

Table 1. Student responses in the gene section

Question (Science concept)	Possible responses	Percentage of students giving response (n=80)
Which analogy best describes what genes are like	Genes are like commanders that control our traits	61.3
What, if any, is the connection between DNA and genes? (can circle more than one answer)	Genes are segments of DNA	7.5
	Genes determine our traits and DNA make us up	
DNA and RNA are made of	Nucleotides	91.3

RNAi section

In this RNAi section, students were asked to "test the knowledge on RNAi" This section had three questions. Question 1 was what it stands for RNAi and surprising slightly more than 50% given the correct answer (Table 2). Being in medical field and not knowing RNAi is nothing to surprise. Student responses to each question are given in Table 2. Because student explanations cannot be aggregated for the entire section, explanations of responses to each question are reported in Table 2. Because question number 3 is not taught at the school level, students were not expected to know this exception. To find out general knowledge among medical faculty students, I have given this question. Andrew Fire and Craig Mello won a Nobel Prize in 2006 for their work does not know by students, extremely sad to say the outcome was only 16.3%. Out of this what I felt is university students must grab knowledge out of the class room. Incorrect explanations was gained in question number 3 mainly to the following Misconceptions, The effectors of gene silencing are short double-stranded RNA molecules produced by the action of the enzyme dicer. Approximately what size are these molecules? Confusion regarding the RNAi size was known by only 10%. These explanations were difficult to categorize. 3rd year (5%); 2nd Year (1.2%); 1st Year (3.8) and 4th Year 0%, and still it shows 3rd year student gain good knowledge after 2nd MBBS level. The students had widespread misconceptions, such as: "No Idea" (student 40 out of 80).

Table 2. Student responses in the RNAi section

Question (Science concept)	Possible responses	Percentage of students giving response (n=80)
'RNAi' stands for which of the following?	RNA interference	52.5
Andrew Fire and Craig Mello won a Nobel Prize in 2006 for their work, begun in the late 1990s, on RNA interference. Which of the following organisms did they work on?	Round worms	16.3
The effectors of gene silencing are short double-stranded RNA molecules produced by the action of the enzyme dicer. Approximately what size are these molecules?	22 bp	10.0

RNAi therapeutic application section

In this RNAi therapeutic application section, students were failed to give a single example for the therapeutic application on this aspect. Only 4% were given at least one example on this section and almost all 96% doesn't know about its therapeutic application. When this study was considered all the section, this section can be ranked as the poorest outcome among all three sections (Table 3). Further questioning revealed that the student's RNAi therapeutic application given answer and when ask the question it also failed in this section. The result of this mechanism occurring in RNAi will have a wide range of therapeutic applications. It may be possible to use microRNAs to silence oncogenes. Which of the following is caused by oncogenes? And the outcome was 63.8% only, gave us a little satisfactory.

It is not clear that this why can transgenes activate RNAi, no doubt it gives 11.3%, and manipulation far will result in 2nd Year (5%); 1st Year (5%); 4th Year 1.3% and 3rd Year 0%, where 3rd year students were unable to answer for this section. The possible "solution" to this difficulty is hinted at in the last part of the excerpt, and when the interviewer explicitly asked how this RNAi could account for the therapeutic application shown in Table 3 and explained. Data from the questionnaire assessment were used to infer students' RNAi application methods. Relationships between latent variables such as given muscle disease and RNAi application obtained 23.8%, and 33.8% respectively. In this study, the latent variables which explained about had a small low outcome but there was a relationship among them. Linkages between these ideas comprise an integrated understanding of RNAi application is poorly known by the medical faculty students at University or Rajarata, need to improve with any cost by modifying the current teaching methodology.

Table 3. Student responses in the RNAi application

Question (Science concept)	Possible responses	Percentage of students giving response (n=80)
There are hopes that RNAi will have a wide range of therapeutic applications. It may be possible to use microRNAs to silence oncogenes. Which of the following is caused by oncogenes?	Cancer	63.8
Why can transgenes activate RNAi (can circle	Their insertion activates	11.3

Question (Science concept)	Possible responses	Percentage of students giving response (n=80)
more than one)	the transcription of miRNAs	
Patients who have a disease called X have over growth in muscle. Scientists know that X is inherited (caused by a gene). Therefore, the gene responsible for X does not contain correct information about:	The composition of muscle tissue	23.8
To cure the above symptoms RNAi therapy can be introduced, what is the main function of it.	RNAi silencing complex to guide mRNA cleavage, so promoting mRNA degradation and reduce over expression of protein	33.8
Give an example of an RNAi therapy which is used current treatment to cure any disease/s	Correct Answer	4
	No Idea	96

4. Discussion

In this study with medical faculty students in Northeastern part of the Sri Lanka, it was observed that 96% of students gave wrong or no idea for RNAi based therapeutic applications. It is not yet clear at what level genetics should be introduced into the curriculum by considering the above results. As discussed by Marbach-Ad and Stavy (Marbach-Ad 2001), arguments are given for its inclusion both before 16 and after 16 yr of age (Shayer 1974). Studies also have shown that difficulties in understanding genetics persist at school, college, and university levels (Marbach-Ad 2001)). These authors suggested that genetics concepts and processes belong to different levels of organization and are not often connected properly. Earlier studies by Lewis *et al.* (Lewis, Leach and Wood-Robinson 2000) and Marbach-Ad (2000) showed that the concepts in genetics are “compartmentalized” and “without providing any conceptual frame work,” which could be a result of teaching methodology. Classical and molecular genetics taught at different levels often are not connected properly, and the gap between the two remains an obstacle to the development of a holistic concept of genetics. Banet and Ayuso (Banet&Ayuso 2003) commented, “From an academic point of view, we consider it important to provide students with a basic conceptual framework for understanding the location, transmission and expression of hereditary information and the basic mechanisms involved in the evolution of living beings. Such knowledge would also help students to understand the biological significance of certain phenomena such as cell division, the reproduction. Finally therapeutic application based on RNAi.”

Various studies and the work reported here indicate that the teaching of genetics needs considerable review and strengthening. Because the abstract nature of genetics is difficult to conceptualize, other teaching aids such as photographs, film and video, time-lapse phase contrast microscopy, models, etc. could be introduced to explain the dynamic nature of the various processes, such as protein production from mRNA messenger. The emphasis in teaching and learning genetics should not be confined to covering the topics and having students memorize them by rote (which, by and large, is what is practiced in a majority of the schools and universities in Sri Lanka, with some exceptions). Instead, genetics teaching should aim to instil conceptual understanding of the subject area and encourage thinking during the learning activities. Only then will students be able to assimilate and accommodate the related information in real-life situations.

Conclusion

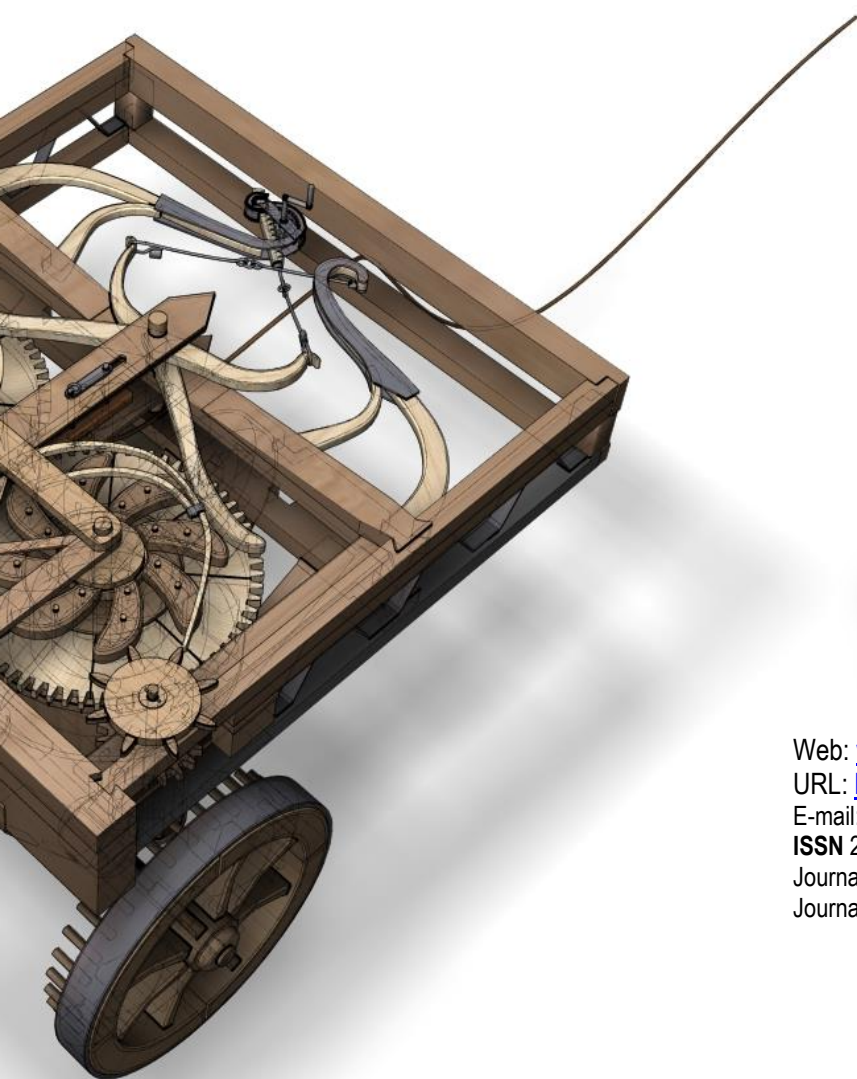
In conclusion, the complex RNAi therapeutic application in this study prompted a more nuanced investigation of students' responses, yielding more insight into student learning about RNAi topics. These research findings have implications for the design of instruction, student-learning materials, assessments, and teacher support materials as well as the research conducted on science teaching and learning. Leveraging this work, future research studies should optimize the contributions of both quantitative analyses of student performance and more in-depth analysis of students' written responses in therapeutic application based on RNAi. Finally, future research studies can contribute to the field by providing more details about science learning and the supports necessary to help students develop a deep understanding about fundamental science topics that affect society with new technology and therapeutic application.

References

- [1] Almeida, R. and R.C. Allshire (2005). "RNA silencing and genome regulation" *Trends Cell Biology* 15(251-258).
- [2] Alozie, N., J. Eklund, A. Rogat and J. Krajcik (2010). "Genetics in the 21st century: The benefits & challenges of incorporating a project-based genetics unit in biology classrooms." *The American Biology Teacher*, 72(4): 225-230.
- [3] Banet, E. and G. E. Ayuso (2003). "Teaching of biological inheritance and evolution of living beings in secondary school." *International Journal of Science Education* 25(3): 373-407.
- [4] Brumby, M. N. (1984). "Misconceptions about the concept of natural selection by medical biology students." *Science Education* 68: 493–503.
- [5] Chattopadhyay, A. (2005). "Understanding of Genetic Information in Higher Secondary Students in Northeast India and the Implications for Genetics Education." *Cell Biology Education* 4: 97-104.
- [6] Davis, I. C. (1948). "Science in functional living." 32(3): 136-137.
- [7] Dawson, V. and R. Schibeci (2003). "Western Australian school students' understanding of biotechnology." *International Journal of Science Education* 25: 57 – 69.
- [8] Duncan, R.G. and B.J. Reiser (2007). "Reasoning across ontologically distinct levels: Students' understandings of molecular genetics." *Journal of Research in Science Teaching*, 44(7): 655-674.
- [9] Duncan, R.G., A.D. Rogat and A. Yarden (2009). "A learning progression for deepening students' understandings of modern genetics. *Journal of Research in Science Teaching*," *Journal of Research in Science Teaching*, 46(6): 655 – 674.
- [10] Hallden, O. (1988). "The evolution of the species: pupil perspectives and school perspectives." *International Journal of Science Education* 14: 541-552.
- [11] Kindfield, A. C. H. (1994). "Assessing understanding of biological processes: elucidating students' models of meiosis." *The American Biology Teacher* 56: 367-371.
- [12] Lewis, J. and U. Kattmann (2004). "Traits, genes, particles and information: re-visiting students' understandings of genetics." *International Journal of Science Education* 26(2): 195-206.
- [13] Lewis, J., J. Leach and C. Wood-Robinson (2000). "All in the genes?—Young people's understanding of the nature of genes." *Biological Education* 34(2): 74-79.
- [14] Longden, B. (1982). "Genetics—are their inherent learning difficulties?" *Journal of Biological Education* 16: 135-140.

- [15] Marbach-Ad, G. (2001). "Attempting to break the code in students' comprehension of genetic concepts." *Journal of Biological Education* 35(4): 183-189.
- [16] Orcajo, T. I. and M. M. Aznar (2005). "Solving problems in genetics II: Conceptual restructuring. International " *Journal of Science Education*, 27(12): 1495 – 1519.
- [17] Shayer, M. (1974). "Conceptual demands in the Nuffield O-level biology course." *Sch. Sci. Rev.* 56: 381-388.
- [18] Tusch, T. (2002). "Expanding small RNA interference." *Nature Biotechnology* 20: 446-447.
- [19] Venville, G., S. J. Gribble and J. Donovan (2005). "An exploration of young children's understandings of genetics concepts from ontological and epistemological perspectives." *Science Education* 89: 614 – 633.
- [20] Wood-Robinson, C., J. Lewis and J. Leach (2000). "Young people's understanding of the nature of genetic information in the cells of an organism." *Journal of Biological Education* 35(1): 29-36.
- [21] Zohar, A. and F. Nemet (2002). "Fostering students' knowledge and argumentation skills through dilemmas in human genetics" *Journal of Research in Science Teaching* 39: 35 – 62.

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ISSN 2068 – 8407

Journal DOI <http://dx.doi.org/10.14505/jres>

Journal's Issue DOI <http://dx.doi.org/10.14505/jres.v5.7.00>