Bioeduca: Journal of Biology Education
http://journal.walisongo.ac.id/index.php/bioeduca
ISSN 2714-8009 (print), 2715-7490 (online)

Volume 7, Nomor 1, Tahun 2025
Hal. 79 – 90

An Analysis of Procedural and Conceptual Knowledge in Genetic Engineering Topic among STEM Students: Basis for Instructional Material Development

Anwar I. Kolong[1]*, Melbert C. Sepe[2]
[1]Ministry of Basic, Higher and Technical Education, Sta. Clara, Lamitan City, Basilan, Philippines
[2]College of Science and Mathematics, Western Mindanao State University, Zamboanga City.
*Email: anwar.kolong@g.msuiit.edu.ph

Article Information
Submited: 06 – 07 – 2024
Accepted: 26 – 03 – 2025
Published: 31 – 03 – 2025

ABSTRAK

Tujuan dari penelitian ini adalah untuk mengkaji tingkat pengetahuan prosedural dan konseptual pada topik rekayasa genetika di kalangan siswa STEM, guna menyediakan dasar dalam pengembangan bahan ajar yang efektif. Topik-topik seperti pengantar rekayasa genetika, kloning gen, dan ekstraksi DNA digunakan untuk menentukan tingkat pengetahuan siswa, baik yang bersifat prosedural maupun konseptual. Penelitian ini menggunakan pendekatan kuantitatif deskriptif dengan instrumen tes sebanyak 12 butir untuk menganalisis dan menilai pengetahuan prosedural dan konseptual. Skala Likert 5 poin digunakan untuk mengukur tingkat pemahaman siswa. Sebanyak 12 siswa STEM dari *Concepcion National High School* berpartisipasi dalam penelitian ini pada tahun ajaran 2023–2024. Hasil penelitian menunjukkan bahwa siswa menunjukkan tingkat kemahiran yang lebih tinggi dalam pengetahuan prosedural dibandingkan dengan pengetahuan konseptual pada ketiga topik: rekayasa genetika, kloning gen, dan ekstraksi DNA. Terdapat variasi tingkat pemahaman yang lebih luas pada pengetahuan prosedural, yang menunjukkan adanya keragaman kemampuan di antara siswa. Sebaliknya, variabilitas yang lebih rendah pada topik ekstraksi DNA mengindikasikan tingkat pemahaman yang lebih konsisten. Ukuran sampel yang kecil membatasi penggunaan metode statistik inferensial, sehingga penelitian ini menekankan pentingnya menemukan metode pengajaran yang lebih efektif untuk meningkatkan pemahaman siswa terhadap konsep-konsep rekayasa genetika. Data kualitatif mengungkapkan adanya kendala yang cukup signifikan, termasuk kurangnya pengalaman dan materi pembelajaran yang bersifat interaktif. Hal ini menegaskan pentingnya keterlibatan aktif siswa serta penyediaan sumber daya yang memadai. Rekomendasi dari penelitian ini mencakup peningkatan kegiatan praktikum di laboratorium, memastikan ketersediaan bahan yang diperlukan, serta penerapan teknik pembelajaran interaktif untuk memperdalam pemahaman siswa terhadap rekayasa genetika.

Penelitian ini menyoroti pentingnya intervensi pendidikan yang komprehensif untuk meningkatkan pengetahuan teoretis dan praktis dalam bidang rekayasa genetika.

Kata kunci: Biologi; Tantangan; Ekstraksi DNA; Kloning Gen; Persepsi.

Publisher	ABSTRACT
Program Studi Pendidikan Biologi, Fakultas Sains dan Teknologi, UIN Walisongo Semarang	*The objective of this study is to examine the levels of procedural and conceptual knowledge in genetic engineering topics among STEM students to provide baseline in developing effective instructional materials. Topics such as introduction to Genetic engineering, Gene Cloning, and DNA extraction were utilized to determine levels of students'types of knowledge, procedural and Conceptual. A descriptive quantitative research approach using 12-item test is used to analyze and assess both procedural and conceptual knowledge using a 5-point Likert scale was used to measure students' understanding. A total of 12 STEM students from Concepcion National High School took part in the study during the 2023-2024 academic year. The findings of the study revealed that students demonstrated higher levels of proficiency in procedural knowledge compared to conceptual knowledge across the three topics: genetic engineering, gene cloning, and DNA extraction. There appears to be a range of understanding levels when it comes to procedural knowledge, as indicated by the higher variability. On the other hand, the lower variability in DNA extraction suggests a more consistent level of comprehension. The study's small sample size limited the use of inferential statistical methods, highlighting the importance of finding more effective teaching methods to improve students' comprehension of genetic engineering concepts. Qualitative data uncovered notable obstacles, including a dearth of interactive experiences and materials, underscoring the importance of active involvement and sufficient resources. Suggestions involve improving laboratory sessions, ensuring the availability of required materials, and implementing interactive teaching techniques to enhance students' understanding of genetic engineering. This study highlights the significance of well-rounded educational interventions to enhance both theoretical and practical knowledge in genetic engineering.* ***Keywords:*** *Biology; Challenges; DNA extraction; Gene Cloning; Perception.*

INTRODUCTION

The Philippines is encountering a notable challenge with decreasing proficiency in mathematics and science, as shown by assessments such as the National Achievement Test (NAT), Trends in International Mathematics and Science Study (TIMSS), and Programme for International Student Assessment (PISA) 2022 where the average score in science is one of the lowest among all PISA-participating countries and economies. Unchangingly, the PISA average scores in 2022 closely resembled those from 2018. There was no improvement in the disparity between the highest-achieving students (top 10%) and the lowest-achieving students (bottom 10%) in Science, according to the PISA 2022 report. Students found difficulties recognizing concepts and theories, which may need further attention to improve instruction and retool educators. Hence, future outlooks and recognizing the urgency of addressing issues and shortcomings in attaining the country's quality primary education (DepEd.gov.ph).

In a typical classroom, genetics can be challenging to teach and learn (Choden & Kijkuakul, 2020). It is a challenging and complicated course to teach, but one that is crucial to understanding many aspects of society, including cloning, genetically modified organisms, DNA testing, and illness detection (NIH, 2010). The results of various research in grades 7–12 indicate that misconceptions regarding various genetics subtopics by teachers and students may cause difficulties (Altunoglu & Seker, 2015; Osman et al., 2017; Yates & Marek, 2013). The students' misconceptions about genetics from a prior lesson or mistakes in the curriculum statement and textbooks made things more complicated (Sanders & Makotsa, 2016).

The subjects students thought were hardest to teach and understand were those connected to molecular biology and biotechnology, such as genetic engineering, gene technology, genetics, cell division, DNA replication, and protein synthesis. Teachers cited several reasons for the difficulty, including a lack of subject matter expertise and visual aids, an overload of curriculum, difficulty planning hands-on exercises, and the abstract nature of the subjects. Instructors recommended that students use 3D animations, virtual laboratories, laboratory supplies, curriculum content reduction, training, and study tours as workable solutions to overcome the challenges (Byukusengeet al, 2022).

Furthermore, the complexity of genetics extends beyond the lab and into larger social contexts. Ethical issues involving genetic research and applications raise deep questions regarding morality, social justice, and responsible technology use. Issues such as informed consent, genetic prejudice, and equitable sharing of benefits and drawbacks highlight the importance of incorporating ethical perspectives into genetic research. Moreover, the convergence of genetics with several domains, such as medicine, agriculture, forensics, and conservation, necessitates cooperative endeavours and transdisciplinary discussions to address complex issues and maximize the benefits to society. Thus, navigating the complex field of genetics requires scientific knowledge, social awareness, ethical understanding, and a dedication to fostering diverse and responsible practices.
One particular area concerned is the extent to which Grade 11 STEM students understand genetic engineering. Given the complexity of the subject, learning effectively in genetic engineering requires both procedural and conceptual mastery. Therefore, this study aims to assess Grade 11 STEM students' procedural and conceptual knowledge of genetic engineering.

METHODS

This study used descriptive quantitative with qualitative support. A validate 12-item accomplishment test will gauge their conceptual understanding and with the used of a 5-point Likert scale rubric to assess the procedural knowledge of the participants. There will be three general parts of the questionnaire; Part-I, Respondents' Profile; Part-II, Student's Procedural Knowledge which constitutes 3 questions on genetic engineering, gene cloning and DNA extraction topic and, Part-III Conceptual Knowledge which constitute nine questions from three major topics. Data analysis techniques like mean, frequency, Spearman's rank correlation, Kendall's tau, and content analysis will be utilized to demonstrate data related to procedural and conceptual understanding as well as students' perspectives on genetic engineering. Moreover, all Concepcion National High School’s STEM students (N=12) that are currently enrolled in S.Y. 2023-2024 have been intentionally considered as generic research participants.

During the process of data collection, the coding mechanism will also be utilized in order to secure the identity of the respondents. For the purpose of maintaining the highest level of confidentiality, coding such as SR-01, which stands for "student's respondents' number one," is utilized.

Procedural and Conceptual Knowledg eMarking Rubric for Genetic Engineering Test. Rubrics were adopted and modified from the study conducted by Chirove, M., & Ogbonnaya, U. I. (2021, October 28) entitled the relationship between grade 11 learners’ procedural and conceptual knowledge of algebra. *JRAMathEdu*

The data collected from the validated questionnaires were analyzed to assess both the procedural and conceptual knowledge of the STEM students in the context of genetic engineering, gene cloning, and DNA extraction. Descriptive statistics, including mean scores and standard deviations, were calculated to summarize the central tendencies and variability in the students' knowledge.To provide a comparative analysis, the mean scores for procedural knowledge in genetic engineering, gene cloning, and DNA extraction were evaluated. These scores were then compared to the mean scores for conceptual knowledge in the same areas. The standard deviations were examined to understand the extent of variation in the students' responses, indicating the consistency or disparity in their understanding.

RESULTS AND DISCUSSIONS

Table 1. Mean scores and Standard deviations (SD) the procedural knowledge in terms of Genetic Engineering

	Mean	SD
Procedural Knowledge on Genetic Engineering	3.28	.3717
Procedural Knowledge on Gene Cloning	3.11	.1625
Procedural Knowledge on DNA Extraction	3.08	.1493

The table 1 presents a comparative analysis of procedural knowledge in the context of genetic engineering, gene cloning and DNA Extraction focusing on their mean scores and standard deviations (SD),. Procedural knowledge, which pertains to the understanding of the processes and techniques involved in genetic engineering, has a higher mean score of 3.28 with a standard deviation of 0.3717 followed by the practical understanding and application of cloning techniques which has a mean score of 3.11 with a standard deviation of 0.1625 and finally the practical skills and techniques involved in DNA extraction which has a mean score of 3.08 with a standard deviation of 0.1493.

The standard deviation is a measure that shows how much the scores deviate or spread out from the mean. A higher level of variability, as seen in the procedural knowledge of genetic engineering (SD = 0.3717), indicates a greater range of understanding among the participants. On the other hand, the smaller standard deviations in gene cloning (SD = 0.1625) and DNA extraction (SD = 0.1493) suggest that the scores are tightly grouped around the average, which suggests a higher level of consistency in practical knowledge and skills among the participants in these particular fields. The variability in standard deviations emphasizes the disparities in the distribution of participants' knowledge across various aspects of genetic engineering.

These findings have significant implications for educational and training programs in genetic engineering. There seems to be a wide range of understanding when it comes to genetic engineering processes. This indicates that there is a need for more focused instructional interventions to ensure that all learners have a consistent understanding of these concepts. On the other hand, the fact that there is less variation in knowledge and skills concerning gene cloning and DNA extraction suggests that the current training methods for these areas may be more effective or standardized. It is important for educators to explore the teaching methodologies utilized in gene cloning and DNA extraction in order to discover the most effective approaches that can be implemented in genetic engineering education. In addition, these valuable insights can assist curriculum developers in effectively allocating resources and designing assessments that target the areas with the most variability.

Table 2. Mean scores and Standard deviations (SD) of students' conceptual knowledge in terms of Genetic Engineering

	Mean	SD
Conceptual Knowledge on Genetic Engineering	2.69	.0829
Conceptual Knowledge on Gene Cloning	2.51	.2310
Conceptuall Knowledge on DNA Extraction	2.45	.1324

Table 2 presents the students' conceptual knowledge, which involves the comprehension of the principles and theories underlying genetic engineering which has a higher mean score of 2.69 , following with the conceptual knowledge, which encompasses the theoretical understanding of the principles and concepts behind cloning, has a mean score of 2.51 with a standard deviation of 0.2310 and finally the understanding of the underlying principles and concepts of DNA extraction, has a lower mean score of 2.45 with a standard deviation of 0.1324.

The standard deviation here also indicates the range of variation in students' comprehension. The higher standard deviation in the conceptual knowledge of cloning suggests a wider range of understanding among the students, in contrast to the more closely clustered scores for DNA extraction. This indicates that while certain students possess a solid understanding of cloning concepts, others may encounter difficulties in comprehending these theories. It appears that students' understanding in the area of DNA extraction is relatively consistent, although the overall average score is lower.

These patterns have important implications for instructional strategies. There is a noticeable difference in the average score and the range of conceptual knowledge in genetic engineering, indicating the importance of using varied teaching methods to accommodate the different levels of understanding among students in the classroom. When it comes to cloning, it's clear that there is a wide range of understanding among students. This suggests that additional resources or focused interventions could be helpful in supporting those who are falling behind. On the other hand, the data shows that students' understanding of DNA extraction is fairly consistent, but there is room for improvement in terms of overall comprehension. Customized teaching techniques and supplementary educational resources could assist in closing these disparities and improving understanding of various subjects.

Table 3. The Difference between the procedural knowledge and conceptual knowledge in terms of Genetic Engineering

Genetic Engineering	Mean	SD	Mean Difference	p-value
Procedural	3.28	.3717	.5808	.000
Conceptual	2.69	.0829		

The table 3 presents a comparative analysis of procedural and conceptual knowledge in the context of genetic engineering, focusing on their mean scores, standard deviations (SD), mean difference, and the associated p-value. Procedural knowledge, which pertains to the understanding of the processes and techniques involved in genetic engineering, has a mean score of 3.28 with a standard deviation of 0.3717. In contrast, conceptual knowledge, which involves the comprehension of the principles and theories underlying genetic engineering, has a lower mean score of 2.69 with a much smaller standard deviation of 0.0829.

The mean difference between procedural and conceptual knowledge scores is 0.5808, indicating that individuals scored higher on average in procedural knowledge compared to conceptual knowledge. This difference is statistically significant, as evidenced by the p-value of 0.000, which is well below the commonly accepted threshold of 0.05. This reflects a true disparity in the levels of procedural and conceptual knowledge in genetic engineering.

The provided data indicates that overall individuals possess significantly higher procedural knowledge compared to conceptual knowledge in genetic engineering, with a substantial and statistically significant mean difference between the two types of knowledge.

Table 4. The Difference between the procedural knowledge and conceptual knowledge in terms of Cloning.

Genetic Engineering	Mean	SD	Mean Difference	p-value
Procedural	3.11	.1625	.5917	.000
Conceptual	2.51	.2310		

The Table 4 provides a comparative analysis of procedural and conceptual knowledge specifically within the domain of cloning, highlighting their respective mean scores, standard deviations (SD), mean difference, and the associated p-value. Procedural knowledge, which involves the practical understanding and application of cloning techniques, has a mean score of 3.11 with a standard deviation of 0.1625. On the other hand, conceptual knowledge, which encompasses the theoretical understanding of the principles and concepts behind cloning, has a lower mean score of 2.51 with a standard deviation of 0.2310.

The mean difference between procedural and conceptual knowledge scores is 0.5917, indicating that individuals score significantly higher on procedural knowledge compared to conceptual knowledge in the context of cloning. The p-value is well below the typical threshold of 0.05, reinforcing the conclusion that there is a genuine and significant difference between the two types of knowledge.In summary, the data reveals that individuals exhibit substantially higher procedural knowledge than conceptual knowledge in the field of cloning, with a significant mean difference and strong statistical evidence supporting this disparity.

Table 5. The Difference between the procedural knowledge and conceptual knowledge in terms of DNA Extraction.

Genetic Engineering	Mean	SD	Mean Difference	p-value
Procedural	3.08	.1493	.6292	.000
Conceptual	2.45	.1324		

The table 5 presents a comparative analysis of procedural and conceptual knowledge in the context of DNA extraction, with a focus on their mean scores, standard deviations (SD), mean difference, and the associated p-value. Procedural knowledge, which refers to the practical skills and techniques involved in DNA extraction, has a mean score of 3.08 with a standard deviation of 0.1493. In contrast, conceptual knowledge, which encompasses the understanding of the underlying principles and concepts of DNA extraction, has a lower mean score of 2.45 with a standard deviation of 0.1324.The mean difference between procedural and conceptual knowledge scores is 0.6292, indicating that individuals have significantly higher procedural knowledge compared to conceptual knowledge in DNA extraction. This difference is statistically significant, as evidenced by the p-value of 0.000. Overall, the data indicates that individuals possess substantially greater procedural knowledge than conceptual knowledge in the field of DNA extraction. The significant mean difference and the extremely low p-value provide strong evidence that this disparity is real and noteworthy. Nevertheless, when students where asked about their perceptions and challenges in learning the concepts , two students frankly stated that its both difficult and challenging on the part of the students and the teacher.

Transcript 1:

Student 05: *“Mahirap poh ang genetics na subject mas lalo na ang genetic engineering, because it requires hands-on activity para maintindihan (peo never poh kami ng lab nun kc). Superficial lng ang pgtuturo ng concepts, more on basic kasi walang materials and available na tools, chemicals sa school that will demonstrate the idea molecularly. Mahirap poh tlga, through videos and powerpoint presentation lng kami naglelearn. Example poh yung sa DNA extraction wla pong activity nun“*

Transcript 2:

Student 08: *….Hard to understand poh is yung cloning the concepts and DNA recombination, we I know how to define it poh but when in actual di ko poh talaga alam pano ginagawa. Through videos and textbook lang ako ngrerely at turo ni teacher.*

The above transcripts highlight the difficulties experienced by students and educators when they lack access to practical laboratory activities and sufficient resources. The use of videos and textbooks for learning has its merits, but it falls short in providing the necessary practical experience and deep conceptual understanding. These limitations underscore the pressing demand for enhanced educational resources and increased opportunities for interactive, experiential learning to bridge the divide between procedural and conceptual knowledge in genetic engineering and related disciplines. Closely addressing these gaps can improve student learning and better position them for post-secondary education and career-related practices.

CONCLUSION AND RECOMENDATION

The mean scores and standard deviations were computed for both procedural and conceptual knowledge. The results indicated that students performed better in procedural knowledge (genetic engineering: M=3.28, SD=0.3717; gene cloning: M=3.11, SD=0.1625; DNA extraction: M=3.08, SD=0.1493) compared to conceptual knowledge (genetic engineering: M=2.69; gene cloning: M=2.51, SD=0.2310; DNA extraction: M=2.45, SD=0.1324). There appears to be a greater diversity in the level of understanding when it comes to procedural knowledge of genetic engineering, as indicated by the higher variability. On the other hand, the lower variability in DNA extraction suggests a more consistent understanding among students. Because of the limited number of participants, it was not possible to use inferential statistical methods. As a result, the analysis was limited to descriptive statistics, which means that the findings cannot be generalized. However, the findings emphasize the importance of implementing more effective teaching methods to enhance students' grasp of genetic engineering, gene cloning, and DNA extraction. This suggests that educational interventions should prioritize strengthening theoretical concepts to ensure a well-rounded understanding of both practical procedures and underlying principles.

The interviews with students regarding their experiences learning genetic engineering revealed significant challenges. Student 05 highlighted the difficulty of the subject and stressed the need for hands-on activities, noting a lack of laboratory sessions and materials, which limited their understanding to basic concepts taught through videos and PowerPoint presentations. Similarly, Student 08 struggled with understanding complex processes like cloning and DNA recombination, relying on videos, textbooks, and teacher explanations without practical engagement. Both students emphasized the necessity of practical, hands-on activities and adequate learning materials to deepen their comprehension. While this study provides a preliminary study on assessing conceptual and procedural knowledge of STEM students, some weaknesses of the study were seen for future improvements of the research, such the questionnaire must run for reliability test and increasing the sample size in order to predict true associations among variables. Moreover, activities such as enhancing laboratory sessions, providing necessary materials, adopting interactive teaching methods, and offering supplementary learning resources to better support students' grasp of genetic engineering concepts has been part of the study's recommendations.

REFERENCES

Altunoğlu, B. D., & Şeker, M. (2015, April 1). The Understandings of Genetics Concepts and Learning Approach of Pre-Service Science Teachers. *Journal of Educational and Social Research*. https://doi.org/10.5901/jesr.2015.v5n1s1p61

Benjamin & Main (2022, January 17). Cognitive Load Theory: A teacher's guide. Retrieved from https://www.structural-learning.com/post/cognitive-load-theory-a-teachers-guide

Baumard, P. (1999). From tacit to explicit, the conjectural pattern of knowing. In P. Baumard (Ed.), Tacit knowledge in organization (pp. 52-77). London: Sage Publication.

Byukusenge, C., Nsanganwimana, F., & Paulo Tarmo, A. (2022, January 4). Difficult topics in the revised biology curriculum for advanced level secondary schools in Rwanda: teachers' perceptions of causes and remedies. *Journal of Biological Education*, *57*(5), 1112–1128. https://doi.org/10.1080/00219266.2021.2012225

Charlesworth, R. (2015, January 19). *Math and Science for Young Children*. Cengage Learning. http://books.google.ie/books?id=mBSdBQAAQBAJ&dq=Charlesworth,+R.,+201

2.+Experiences+in+math+for+young+children.+Belmont,+CA:+Wadsworth+Cengage+Learning.&hl=&cd=2&source=gbs_api

Choden, T., & Kijkuakul, S. (2020). Blending Problem Based Learning with Scientific Argumentation to Enhance Students' Understanding of Basic Genetics. *International Journal of Instruction,* 13(1), 445-462. https://doi.org/10.29333/iji.2020.13129a

Desimone, L.M., T.M. Smith, S.A. Hayes and D. Frisvold, 2005. Beyond accountability and average mathematics scores: Relating state education policy attributes to cognitive achievement domains. Educational Measurement: Issues and Practice, 24(4): 5-18.Available at: https://doi.org/10.1111/j.1745-3992.2005.00019.x.

Dudlicek, L.L., Gettig, E.A., Etzel, K.R., & Hart, T.C. (2004). Status of genetics education in U.S. dental schools. Journal of Dental Education, 68(8):809-818.

Etobro, A. B., & Banjoko, S. (2017, November 1). Misconceptions of genetics concepts among pre-service teachers. *Global Journal of Educational Research,* 16(2), 121. https://doi.org/10.4314/gjedr.v16i2.6

Geary, D.C., 2004. Mathematics and learning disabilities. *Journal of Learning Disabilities,* 37(1): 4-15.

Hiebert, J. and P. Lefevre, 1986. Conceptual and procedural knowledge in mathematics: An introductory analysis. In J. Hiebert (Ed), Conceptual and procedural knowledge: The case of mathematics. Hillsdale, NJ: Erlbaum. pp: 1-27.

Hiebert, J., J.W. Stigler, J.K. Jacobs, K.B. Givvin, H. Garnier, M. Smith, H. Hollingsworth, A. Manaster, D. Wearne and R. Gallimore, 2005. Mathematics teaching in the United States today (and tomorrow): Results from the TIMSS 1999 video study. Educational Evaluation and Policy Analysis, 27(2): 111-132.Available at: https://doi.org/10.3102/01623737027002111.

Jiamu, C. (2001). The great irnportance of the distinction between declarative and procedural knowledge. Análise Psicológica, 19(4), 559-566. doi: 10.14417/ap.362.

Jazuli, A., P. Setyosari and K.D. Sulthon, 2017. Improving conceptual understanding and problem-solving in mathematics through a contextual learning strategy. Global Journal of Engineering Education, 19(1): 49-53. Retrieved from: https://www.researchgate.net/publication/323111425_Improving_conceptual_understanding_and_problem-solving_in_mathematics_through_a_contextual_learning_strategy

Mutawah, M. A. A., Thomas, R., Eid, A., Mahmoud, E. Y., & Fateel, M. J. (2019). Conceptual Understanding, Procedural Knowledge and Problem-Solving Skills in Mathematics: High School Graduates Work Analysis and Standpoints. *International Journal of Education and Practice*, *7*(3), 258–273. https://doi.org/10.18488/journal.61.2019.73.258.273

NIH. (2010). The new genetics. U.S.A: Office of Communications and Public Liaison. National Institute of General Medical Sciences.National Institutes of Health.U.S. Department of Health and Human Services.

Osman, E., BouJaoude, S., & Hamdan, H. (2016, May 6). An Investigation of Lebanese G7-12 Students' Misconceptions and Difficulties in Genetics and Their Genetics Literacy. *International Journal of Science and Mathematics Education*, *15*(7), 1257–1280. https://doi.org/10.1007/s10763-016-9743-9

Rittle-Johnson, B. and M.W. Alibali, 1999. Conceptual and procedural knowledge of Mathematics: Does one lead to the other? Journal of Educational Psychology, 91(1): 175-189.Available at: https://doi.org/10.1037/0022-0663.91.1.175.

Sahdra, B., & Thagard, P. (2003). Procedural knowledge in molecular biology. Philosophical Psychology. 16(4), 477-498.

Sanders, M., & Makotsa, D. (2016). The possible influence of curriculum statements and textbooks on misconceptions: The case of evolution. *Education as Change*, *20*(1). https://doi.org/10.17159/1947-9417/2015/555

Shirani Bidabadi, N., Nasr Isfahani, A., Rouhollahi, A., & Khalili, R. (2016). Effective teaching methods in higher education: Requirements and barriers. Journal of Advances in Medical Education & Professionalism, 4(4):170-178.

Tekkaya, C., 2002. Misconceptions as barrier to understanding biology. Journal Science Education. 23: 259-266.

Yates, T. B., & Marek, E. A. (2013, March 26). Is Oklahoma really OK? A regional study of the prevalence of biological evolution-related misconceptions held by introductory biology teachers. *Evolution: Education and Outreach*, *6*(1). https://doi.org/10.1186/1936-6434-6-6

Zulnaidi, H., & Zakaria, E. (2012, August 17). The Effect of Using GeoGebra on Conceptual and Procedural Knowledge of High School Mathematics Students. Asian Social Science, 8(11). https://doi.org/10.5539/ass.v8n11p102