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Enhancing better understanding of basic Genetics among grade nine students of Dechencholing Higher Secondary School through Scientific Argumentation

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Abstract

In order for the students to think like scientists, they should learn to argue scientifically. The objective of this classroom action research was to use scientific argumentation as an intervention to clarify the misconceptions in the domain of basic Genetics and also to investigate the progression of their class 9 students' scientific argumentative skills by the end of five cycles of action research: planning, acting, observing, and reflecting which was observed for six weeks. The research participants were grade 9 students (n=31) of a secondary school in Bhutan where the researcher is currently teaching. The tools used were the pre- and post- questionnaires, lesson plans, semi-structured observations, pre- and post- semi-structured interviews, reflective journals, and student learning tasks. Content analysis and method triangulation were used to derive the result of the intervention. Although there were few challenges in carrying out the research, nevertheless the results were promising that scientific argumentation not only helped students to clarify their misconceptions but helped them to understand difficult concepts in Genetics. Scientific argumentation could also be used for improving students' confidence and also help them explore more on various topics of their interest in any other subjects. This research helped the researcher to become a better facilitator and learnt many new developments in Genetics as students presented their claim with evidence and justifications.

Keywords: Classroom action research, genetics, scientific argumentation

INTRODUCTION

The student-centered teaching and learning design of the new Bhutanese science curriculum aims to empower students with scientific knowledge and a deep understanding of natural science (DCRD, 2011). Despite the curriculum developers' intentions for a dynamic and student-engaging approach, the prevailing reality reveals that many teachers continue to resort to the traditional lecture method as it appears more convenient (Namgyel, 2005). Likewise, students, influenced by centuries of established classroom culture, emerges between the desired goals of the curriculum and the actual practices within the classroom setting (Dolma et al., 2018).

Genetics is the most difficult but at the same time an interesting topic in Biology as it revolves around human existence. It is fascinating to discover what humans can do with the knowledge of genetics. Kılıç and Sağlam (2014) in their study conducted with 231 secondary education students in Turke, found that although the study of Genetics demands high levels of reasoning, students often lacked a solid comprehension and resorted to rote learning.

In 2016, Bhutan incorporated Genetics into its science curriculum for grades 9-12, encompassing inheritance, variation, genetic engineering, cloning, and evolution to be taught in grade 9 (Royal Education Council, 2016). Despite its inclusion, there has been limited investigation into students' conception and misconceptions related to these topics. Notably, two recent studies focusing on grade 10 and grade 11 students, conducted by Dorji in 2015 and 2017, respectively, exposed prevalent misconceptions and challenges on comprehending the more intricate genetic concepts among the students.

Topics on which students are assessed for their misconceptions are in connection to the day-to-day problems that students face on these subtopics of Genetics and Evolution, such as the relationship between DNA, gene and chromosomes (Genetic inheritance), Genetically modified organism (Genetics), Cloning (Genetics) and Origin of man in evolution.

Assessment of the concepts was done using Genetics and Evolution questionnaires (GEQ) which had 10 regular MCQ with four answers and 5 two tier questions to clarify doubts, developed with the help of a subject expert in science education along with semi-structured observation and semi structured interview.

There were misconceptions among students regarding Basic Genetics in a secondary biology class in Bhutan, as discovered through pre-test analysis and semi-structured interviews conducted before the intervention. The researcher contemplated the idea of allowing students to explore and find answers themselves, thereby facilitating their discovery and learning in the field of Genetics. Consequently, two groups of ninth-grade students were presented with open-ended questions in Genetics and were instructed to come prepared for the following class.

During the subsequent class, the students were engaged in a debate. Despite both teams being well-prepared and performing competently in the debate, several limitations among the students became evident. Firstly, a majority of them exhibited shyness and lacked confidence. Secondly, their exploration of the topic appeared to be limited to what is written in their text book. Thirdly, numerous misconceptions were prevalent among them. Lastly, they encountered difficulties in adhering to the norms of a proper debate. As a result, even by the end of the debate, they were unable to reach a conclusion due to the presence of baseless arguments. Regrettably, the debate left most of them even more confused than before. This marked the inception of the problem statement, underscoring the urgency to educate students on how to engage in scientific arguments, thereby encouraging deeper exploration and enhanced understanding.

The aim of the study was to assess the effectiveness of the scientific argumentation approach in enhancing students' understanding of Basic Genetics which is being introduced in grade 9, aligning with the student–centered focus on facilitating fundamental comprehension. To achieve this objective, classroom action research was conducted, implementing the scientific argumentation approach and carefully structuring the topics for argumentation to emphasize practical application of Genetic with teacher researcher as the facilitator and an observer to achieve another objective of observing an improvement of students' scientific argumentative skills in five cycles of classroom action research.

So in this study, ninth grade students were selected as basics of genetics and evolution is introduced to for the first time and if the misconceptions are clarified at their level than they will understand more as they go to higher grades and be aware of scientific argumentation.

LITERATURE REVIEW

Recently, Bhutan has developed a new science curriculum framework which is student-centered and this revised science curriculum emphasizes the importance of inquiry-based, constructivist and investigative approaches to the learning of science, with the aim to develop the students' scientific knowledge, skills and dispositions and to enable them to think and act scientifically, understand the power of science to explain the natural world and appreciate the effects of science (Das et al., 2017)**.**The study suggests that teaching genetics and natural selection should begin in seventh grade, but due to limited reasoning ability, tenth graders show better problem-solving skills. Complex genetic concepts require matured students with abstract thinking for improved understanding of genetics and evolution (Araz & Sungur, 2007).

Students should comprehend science's capabilities and constraints in dealing with ethical, social, and environmental matters. They must grasp collaborative scientific processes and recognize potential conflicts arising from new knowledge in diverse cultural and religious settings. Existing literature argue that during investigations, students need to adeptly choose, plan, and assess various information sources to draw valid conclusions (Das et al., 2017; DCRD, 2011).Teaching evolution is challenging due to controversy, religious views, and complex biological terminology. While studies explore difficulties in comprehending and accepting evolution, few focus on improving classroom understanding. Genetics understanding is deemed beneficial for grasping evolution (Tibell & Harms, 2017).

The Bhutanese National Curriculum expects ninth-grade students to grasp Genetics and Evolution fundamentals to aid comprehension of advanced topics in higher grades (Royal Education council, 2016). However, several studies done to find out the students' misconception in Genetics concepts (Altunoğlu & Şeker, 2015; Mustami, 2016; Nusantari, 2014; Osman et al., 2017) and Evolution concepts (Putri et al., 2017; Sanders & Makotsa, 2016) and on both (Queloz et al., 2017), revealed that most students across grade 7 till 12 have misconception on various subtopics in Genetics and Evolution.

Argumentation involves presenting claims with evidence to establish positions based on knowledge and beliefs. It was not just disputes but also a transformative process in education, fostering idea clarity, personal growth, and learning (Halimatuz et. al., 2017).Crafting supported statements with elements like claims, evidence, support, qualification, and rebuttal is integral (Toulmin,2003).

Argumentation has gained prominence in contemporary scientific education since the late 1980s due to its positive impact on cognitive processes, communication, critical thinking, and comprehension of scientific practices and reasoning. This significance is underscored by its incorporation into the Next Generation Science Standards (NGSS). By promoting compelling discussions and emphasizing the role of valid reasoning and evidence, argumentation challenges the perception of science as a collection of facts (Ford & Wargo, 2012; Osborne, 2014).

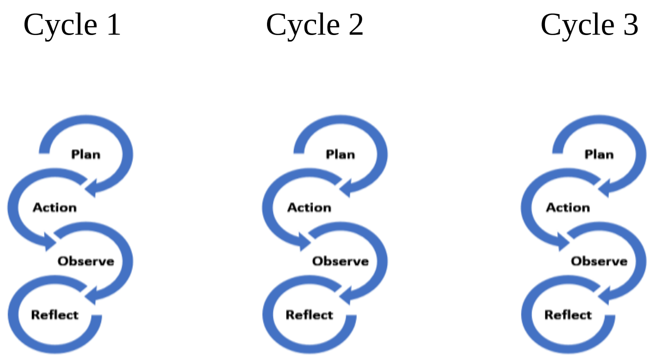
Osborne (2014) identifies three argument forms within science, illustrating their pedagogical value in fostering advanced cognitive skills and transforming science education for deeper understanding and learning.

Employing dialogue to foster argumentation skills aligns with Vygotsky, Mead, and Bakhtin's constructivist theories. Teachers and learners improve their understanding through thought-provoking questions and debates, aiding students in refining argumentative prowess. Mastery requires grasping argumentation theory, consistent practice, and a reflective approach. Argumentation components play a key role in learning, enabling engagement, response, warrant articulation, and idea evaluation (Aldona Augustinienė, 2010; Baumberger et al., 2015; Sampson et al., 2013)

This study adopts Toulmin's (2003) argumentation pattern, where students construct arguments comprising a claim, evidence, reasoning, and rebuttals. These components are presented on a shareable medium like a whiteboard. The 'claim' signifies a conclusion or answer to a research question. 'Evidence' refers to measurements or observations supporting the claim's validity. 'Reasoning' justifies how evidence supports the claim, while 'rebuttals' counter opposing reasoning or evidence. Rebuttals aim to invalidate opposing arguments by introducing reasoning and evidence to undermine their effect. This approach facilitates structured and collaborative argument development, enhancing critical thinking and communication skills in students.

METHODS

According to Hien (2016), it was Kurt Lewin, a German social psychologist who introduced action research as an alternative to experimental methods due to their limitations. Action research involves studying and comparing various forms of social action, aiming for practical solutions. Lewin described it as a cycle of planning, action, and result analysis. In teaching, action research involves identifying classroom issues, finding effective solutions, and sharing successful strategies with colleagues. It offers a continuous process to attain desired outcomes. Employing classroom action research, where the teacher-researcher's active involvement allows for observation and analysis, the study adopted Kemmis and Taggart's research design (2005) for its practicality and consistency in the research process where each cycle has four steps of plan, action, observe and reflect until an effective solution is found.



Research context

The researcher holds a Bachelor's in Education (Secondary Science) from Samtse College of Education (2002) and a Master's in Science Education from Naresuan University, Thailand (2019). With 21 years of teaching experience across seven schools, including remote ones in Bhutan, the researcher noted students' lack of scientific argumentation skills. The researcher is currently teaching in a higher secondary school located in the capital of Bhutan with students from diverse background. Recognizing the importance of thinking like scientists through scientific argumentation, the study focused on grade 9 Genetics and Evolution topics, known for misconceptions due to complexity. The problem statement involved teaching students to argue scientifically to enhance their understanding.

Participants

The study involved 31 Grade 9 students from a secondary school in Bhutan, comprising 14 males and 17 females. These participants were randomly selected from one section of three grade nine sections which encompassed students with varying levels of abilities. While hailing from middle-income families with different mother tongues, however English was used as the medium of instruction in the classroom.

Research instruments

The data collection instruments employed in the study encompassed several components: 5 meticulously designed lesson plans comprising 15 teaching periods, with each 3-period cycle guided by expert-verified plans; a reflective journal capturing researcher’s observations across 5 cycles and a critical friend's insights; pre- and post-questionnaires with 13 two-tiered multiple choice questions exploring genetics concepts and requiring justification; pre- and post-semi-structured interviews guided by the same subtopics as the questionnaires to deepen understanding and validate responses; and student learning tasks, including homework, worksheets, group discussions, presentation charts, reading, research evidence, and notes, Semi structured observations to observe students' progression of scientific argumentation throughout the cycle using worksheets for the students and the observer by Sampson(2013).Prior to implementation, subject experts vetted all instruments, with lesson plans reviewed by biology and science education experts, enhancing the reliability of the instruments employed.

Data Collection

A teaching intervention comprising 15 sessions, each lasting 50 minutes, was conducted. Initial questionnaires were administered to assess students' foundational understanding of genetics concepts. Similar post-intervention questionnaires were given at the genetics unit's conclusion. Responses from both sets of questionnaires were coded and tabulated to determine the frequency of five codes, revealing students' conceptions, misconceptions, or lack of understanding. Similarly the verbatim transcription of pre and post intervention interview were coded for analysis.

A reflective journal along with worksheets from the semi structured observations throughout five cycles were maintained. Additionally, students' learning tasks encompassed homework assessment, presentation charts, group work, follow-up tasks as well as receiving worksheets and activity sheets to monitor teaching and learning progress.

Data analysis

Student responses from both the genetics questionnaires and semi-structured interviews underwent transcription, coding, and content analysis. This entailed categorizing student responses in the questionnaire into five codes (as per Table 1), followed by in-depth reading to identify misconceptions and adapt lesson activities accordingly. The frequencies of these codes were grouped to reveal response patterns across all subtopics, and subsequent reviews sought emerging patterns. The research's credibility was reinforced by employing various data collection methods questionnaires, interviews, observations, reflective journals, and student tasks employing method triangulation to ensure robust results. Peer debriefing involved cooperative examination of research data, the final report, and methodology by a science educator. The analysis database encompassed verbatim transcriptions of pre- and post-intervention interviews, coded using the same five codes and tabulated for comparative understanding of genetics concepts post-intervention. In result analysis and discussion, three main codes such as complete understanding (CU), misunderstanding (M) and no understanding (NO) were focused upon, as they sufficiently addressed the research question, particularly evident in the post-intervention questionnaires and interviews.

FINDINGS

The 5 classroom action research cycles below describe the progression of students' scientific argumentative skills along with the clarification and better conception of basic Genetics being reflected upon and solved in the next cycle.

Students' progression in* Genetic *concepts

The result of the analysis of the pre and post-intervention questionnaires, supported by the analysis of the interviews, was that the intervention helped to understand the basic concepts of genetics and clarified most of the misconceptions. The summary of the results is illustrated in Table 1.

Table 1*: Codes for analysis*

		CU		PU		PU+MU		MU		NO	
	Sub-topics	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
1	Inheritance	3	16	4	4	1	10	4	10	89	61
2	Variation	4	22	19	1	4	13	31	5	41	59
3	Genetic Engineering	10	69	6	0	3	5	16	6	65	19
4	Cloning	13	55	32	10	13	10	6	3	35	23
5	Evolution	3	35	0	3	6	3	71	32	19	26

Note: *CU (Complete understanding): The student has a level of understanding similar to a scientist. PU (Partial understanding): The student has some ideas similar to a scientist. PU+MU (Partial understanding with misconception): The student has some ideas similar to a scientist but they also have misconceptions. MU (Misunderstanding): The student does not have ideas similar to scientists and has misunderstandings. NO (Don't understand): The student has no ideas about the concept or did not write anything.*

The overarching findings highlight three main categories: complete understanding, misunderstanding, and no understanding, as detailed in Table 1. Students' post-genetic questionnaires demonstrate comprehensive grasp of topics in the order of genetic engineering, cloning, evolution, variation, and inheritance. Notably, post-intervention, students exhibited significant improvement in complete understanding across all subjects. Pre-intervention questionnaires showed misunderstandings primarily in evolution, variation, genetic engineering, cloning, and inheritance. Comparison of pre- and post-intervention scores indicated positive progress across all topics. While initially unfamiliar with genetics, post-test results indicated broad comprehension, albeit influenced by challenging distractors in multiple-choice answers.

Students' progression in scientific argumentation

Throughout the intervention, the students' Argumentative skills (AS) exhibited gradual enhancement across the four observation instances, suggesting an impactful influence on students' conception of basic Genetics. While the improvement was not highly substantial within the brief intervention, it still positively affected the students' AS practice. The researcher noted initial challenges in conveying scientific argumentation, despite explanations and provision of observation sheets detailing AS components and assessment methods.

Progression result of students' argumentative skills

First texts, then only figure or table

During the initial observation (see figure 1 below), students were tasked with presenting a diagram illustrating the relationship between Genes, DNA, and chromosomes. However, their grasp of argumentative skills (AS) proved limited; they struggled to confidently articulate their chosen diagram's appropriateness. Many referenced a complex figure (8.1) from their textbook, hindering comprehension for beginners in Genetics and Evolution. While some found suitable online diagrams, they hesitated due to shyness and lack of confidence in facing the audience. Justification scores were minimal as students lacked presentation skills, hesitated with scientific terms, and struggled to pronounce words like "deoxyribonucleic acid" and "chromosomes." Their efforts necessitated extending the presentation to the next day. Scores were negligible, with presenters using fewer than five scientific terms and lacking evidence or strong justifications. They were advised to practice scientific terms, watch relevant videos, and cite valid sources for justifiable evidence

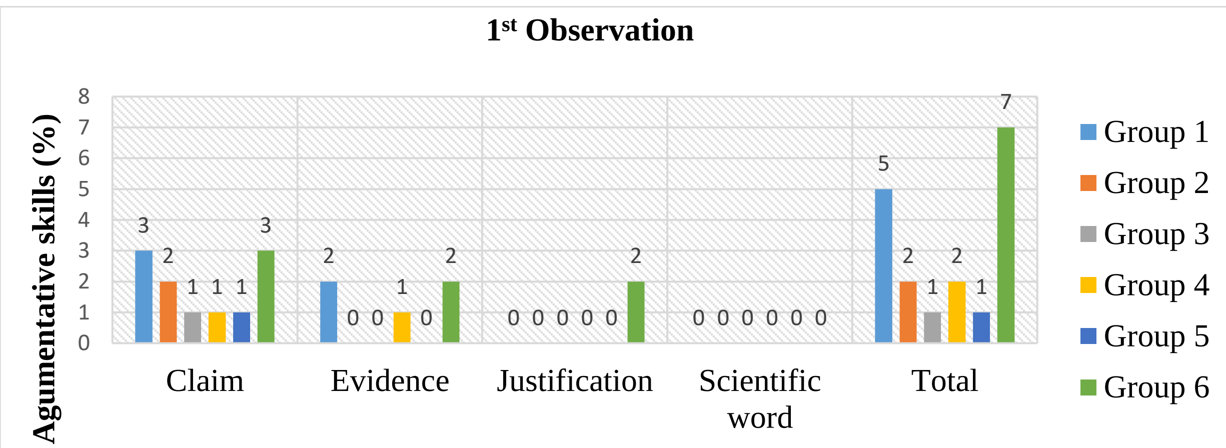


Figure 1: Progression of argumentative skills in the first observation

During the second observation (see Figure 2), all six groups exhibited an improved ability to collectively recognize and decide upon the best solution for the problem at hand. However, challenges persisted in locating evidence, as some students remained unfamiliar with internet research and struggles emerged with aligning claims and evidence. The teacher-researcher intervened to aid groups in finding appropriate sources and understanding the story, while also noticing that Huntington's disease problem generated enthusiasm and engagement. Despite tiredness, students energetically discussed issues in groups and found solutions, with the presentation phase initiating argumentative skill practice. Justifying their solutions posed initial awkwardness, yet groups attempted to support their claims with evidence and justification, fostering lively and insightful classroom interactions. Reflecting newfound understanding, students realized the necessity of valid claims backed by evidence and justification. Improvement opportunities were identified, including enhancing vocabulary and presentation readiness, and facilitating a structured presentation sequence. Additionally, students were prompted to underline challenging terms, research their meanings, and record over five scientific words along with definitions. A lead presenter role was suggested for improved coordination during presentations.

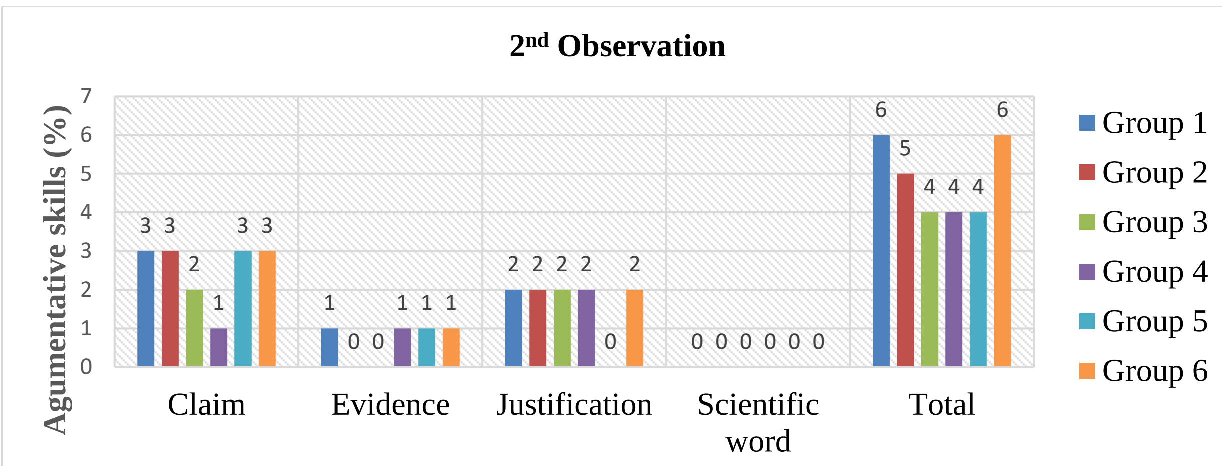


Figure 2: Progression of argumentative skills in the second observation

In the third observation (see Figure 3), students displayed improved mastery of argumentative skills, covering all components except proficient use of scientific terminology. Enhanced competitiveness was seen among various groups, showcasing increased comfort and confidence during presentations. Though claims were strong, limited data-based evidence and weaker justifications were apparent, and only two groups used over five scientific terms. Notably, students engaged in a spirited discussion about genetically modified food's potential for self-sufficiency, citing global genetically modified organism (GMO) adoption rates and yield increase. Counterarguments emphasized health concerns like low fertility rates and cancer risk. Economic dynamics also surfaced, as smaller farmers suffered from GMO's popularity, while some countries considered labelling GM foods. The students' interest in these non-syllabus current topics was palpable, reflecting their significant learning.

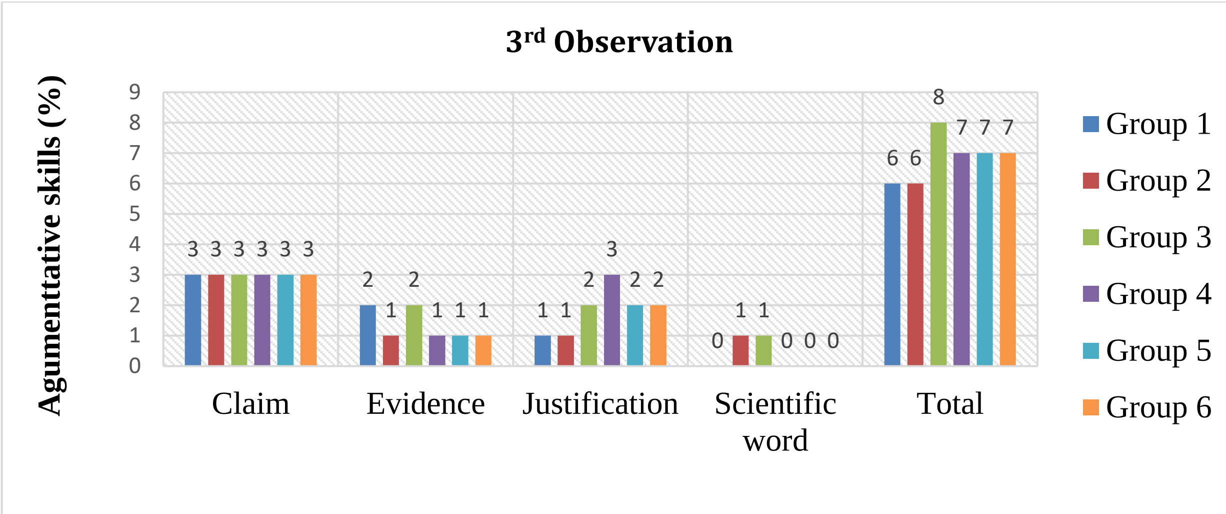


Figure 3: Progression of argumentative skills in the third observation

In the fourth observation (see Figure 4), substantial progress was evident across all six groups, yet ample room for improvement remained, particularly concerning evidence and justification presentation. While group members could assist presenters, challenges persisted with scientific word usage, pronunciation, and meaning. However, participation, independent learning, and autonomy in activity execution notably improved. Students displayed familiarity with the process and information search. Continuous involvement and questioning by the researcher ensured proper engagement. As accountability was shared, students collaborated, fostering teamwork. The fourth observation centered on cloning and evolution, revealing divided opinions on whether monkeys were human ancestors. Group six notably excelled, achieving a score of 9 out of 11 due to robust evidence and justification.

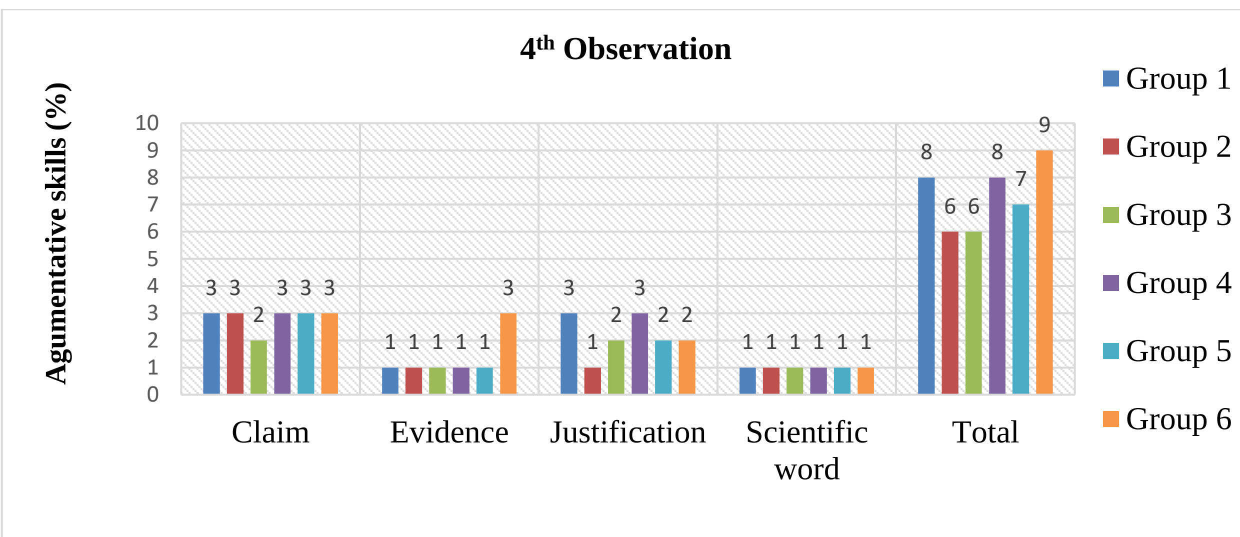


Figure 4: Progression of argumentative skills in the fourth observation

The Figure 5 below illustrates students' scientific argumentation skill progression over four observations. Initially, the total score was 18 out of 66, rising to 29 in the second observation. Subsequent improvement and support led to 41 points in the third observation and a final collective score of 44 out of 66 in the last observation.

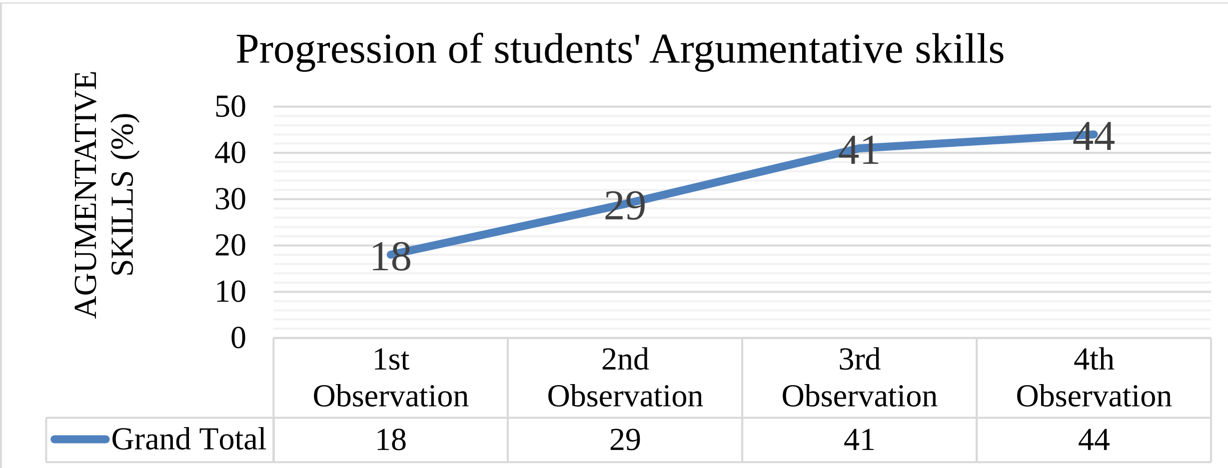


Figure 5: Progression of argumentative skills in all four observations

DISCUSSION

The Figure 5 above, reflecting four observations, portrays a progressive enhancement in scientific argumentation skills. This concurs with Jimenez's observation that students were enthusiastic and engaged, experiencing improved argumentative skills and newfound understanding of Genetics and Evolution concepts. The approach fosters student-centered learning, developing both 21st-century skills and foundational subject knowledge. This method equips students to tackle more advanced content effectively.

The lesson's challenge lay in incorporating argumentation to foster student participation, achieved by providing supplementary reading materials and internet links. Classroom action research proved reflective and cost-effective, progressively reducing the researcher's teaching involvement. By Cycle V, students demonstrated autonomy, confidence in presentations, and collaborative group work. These outcomes paralleled findings of Cavagnetto (2010) reinforcing the approach's efficacy.

An optimistic interpretation of the pre- and post-test results indicate the intervention effectively improved students' grasp of genetics. These findings primarily imply that "Inheritance" was the most challenging topic, followed by variation and then evolution for students at this level. Several factors could contribute to this outcome. Perhaps the topic's introduction coincided with the initial cycle focused on strategy rather than concepts. The approach's novelty for both teachers and students might have overshadowed the topic's significance. Learning the new strategy with limited prior comprehension of the topics in genetic have consumed more time than allotted for this study.

CONCLUSION AND RECOMMENDATIONS

This Scientific argumentation approach taught the students the importance of validating the information or misconceptions especially in the Genetics and Evolution topic as this is where a lot of confusion lies. This model facilitated reflection on teaching methods and students' progression in both conception and scientific argumentative skills through the spirals of classroom action research. Each cycle's reflections informed improvements in subsequent cycles, driving the study's objectives. Scientific argumentation as an intervention altered the traditional teacher mind set, revealing the value of active teaching and learning for complex subjects like genetics. The approach highlighted the teacher's role as a facilitator in implementing successful student-centered active learning strategies, collaborating with the findings of Jimenez-Aleixandre et al. (2010).

At the outset, significant time was dedicated to simultaneously teaching the components of the scientific argumentation, yet once students grasped the procedural aspects, conceptual learning became smoother. Another recommendation is to allow students to use smart phones for such lessons to enable them to explore more on the concepts taught. It is important to acknowledge that this study's scope encompassed a Genetics-focused intervention for grade 9 students in one school, spanning six weeks. Consequently, there is a necessity for replicating this research, particularly within science education, and share the findings in educational professional development settings.

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