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Research Article

Empowering STEM Educators: Evaluating the Impact of an OER Module on Genetics and Heredity in Biology Classrooms

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ABSTRACT: ***The study investigated the effectiveness of the "Introduction to Genetics and Heredity" Open Educational Resources (OER) module, designed by Samtse College of Education in collaboration with the Ministry of Education and Skills Development, as part of a Training of Trainers (ToT) Professional Development (PD) training for secondary STEM teachers. The six-week course, which used a blended learning approach, included 38 biology teachers. The focus was to enhance subject knowledge, pedagogical content knowledge (PCK), and promote inclusivity using the Universal Design for Learning (UDL) framework. The module's impact was evaluated through pre- and post-tests, lesson plans development, reflective writing, peer assessments, and video Lesson. The post-test results revealed a slight decline in performance compared to pre-test scores, with no participants achieving the "Accomplished" level. The majority remained at the "Proficient" level, while three participants moved to the "Novice" category. Qualitative analysis of lesson plans and reflections highlighted participants' use of technology, inclusive pedagogy, and active learning strategies. Statistical findings showed strong alignment with key educational themes, such as active learning (mean = 1.46, SD = 0.56) and multiple content representations (mean = 1.54, SD = 0.51). The study identified the need for advanced content and better alignment between the pre- and post-tests and the module objectives for sustained teacher improvement in genetics education.***

KEYWORDS: ***Pedagogical Content Knowledge (PCK), Inclusive Pedagogy, Universal Design for Learning (UDL), Open Educational Resources (OER), Student Engagement.***

INTRODUCTION

The module on Introduction to Genetics & Heredity was curated by Biology teacher educators at Samtse College of Education in collaboration with Biology curriculum developer from the Department of Curriculum and Professional Division (DCPD), Ministry of Education and Skills Development (MoESD). The course content for this module was designed using Bhutan's Science Curriculum Framework for Key Stages III and IV. This module aimed to support the professional development of participating teachers by enhancing their subject matter knowledge, pedagogical content knowledge (PCK), use of technology, and inclusive pedagogies to accommodate the learning needs and abilities of all learners. The content in the module is expected to enhance teachers' understanding of genetics and hereditary, associated concepts, as well as their pedagogical knowledge of teaching the concepts. Apart from PCK, the module is designed by incorporating the principles of Universal Design for Learning (UDL) to make Biology teaching and learning inclusive, accommodating the learning needs and

abilities of diverse learners. Similarly, this module emphasizes the use of technology in teaching, learning, and assessments.

TIMELINE OF IMPLEMENTATION

According to the research calendar, the module was scheduled for a six-week implementation.

LEARNING OBJECTIVES

At the end of the module, participants were expected to:

(i) explain the basic principles of genetics;
(ii) draw and describe the detailed structure of chromosome;
(iii) distinguish the types chromosome based on function and structure;
(iv) elaborate the detailed composition of chromosome;
(v) explain the causes of variation and its impact on the phenotype of an organisms;
(vi) outline the steps involved in genetic engineering;
(vii) explain the principles and the steps involved cloning; and
(viii) contextualise the application of genetic engineering to their day-to-day life.

METHODOLOGY

Number of units

Three units namely basics of genetics, variation and inheritance, introduction to concepts of cloning, selective breeding and genetic engineering.

Concepts covered

Genetics, gene, dominant & recessive allele, sex chromosomes, autosomes, karyotype, nucleotides, bases, sister chromatid, non-sister chromatid, inheritance, variation, genetic engineering, cloning

Resources - activities, readings

The activities included were MCQ, Interactive Videos, Discussion, Drag and Drop, Quiz. Wherever required and possible PDF materials were provided to enhance understanding of concepts. Further, some videos were also made available to enhance understanding of the concepts.

Nature and purpose of assessments

Formative and summative assessments were employed throughout the module to evaluate the participants' learning progress. The module began with a mandatory pretest consisting of 45 multiple-choice questions (MCQs) focused on three key themes: learners, content, and teaching-learning. Participants were required to complete this pretest within one hour before proceeding with the module. Each of the four units included various formative assessment activities such as quizzes, short answer writing, reflections, and practical activities with students. At the end of the module, participants were required to complete a similar 45-MCQ posttest, also within an hour. Additionally, participants had to submit two lesson plans on concepts related to the module's content and one reflection after implementing these lesson plans. Beyond tutor assessments, participants' lesson plans and recorded teaching sessions were evaluated by an assigned peer. Out of the 38 teachers involved, eight were selected as a focus group sample. Their lesson plans and teaching were evaluated by the tutor, officials from the

Ministry of Education and Skills Development (MoESD), and their supervisors. All evaluations were conducted using a standardised rubric that emphasised learners, content, and teaching-learning effectiveness.

Methodology

The methodology for this study involved the implementation and evaluation of a Training of Trainers (ToT) Professional Development (PD) workshop aimed at secondary school STEM teachers. The workshop, part of the CL4STEM project, focused on integrating technology into STEM education and was conducted in collaboration with the Ministry of Education and Skills Development (MoESD) at Samtse College of Education (SCE).

Participant Selection

A total of 245 applications were received for the ToT PD workshop. A selection panel evaluated the applicants through a comprehensive review process, considering their qualifications, experience, and leadership capabilities relevant to the workshop's objectives. Of the applicants, 160 were selected, with 40 participants allocated to each of the four STEM disciplines: Biology, Chemistry, Physics, and Mathematics. The participants were required to demonstrate their professional expertise and readiness to contribute to the workshop's goals.

OER Module Implementation

The workshop featured the Open Educational Resources (OER) module titled "Introduction to Genetics and Heredity" for Biology. This module was delivered over six weeks via the Virtual Learning Environment (VLE). During the six-week period, participants engaged in a range of activities designed to develop their knowledge and pedagogical skills in teaching genetics. These activities included:

- Pre-tests and Post-tests: Participants completed pre-tests before starting the module and post-tests at the end of the module to assess their learning progress.
- Module Activities: Engaging with interactive learning content on genetics and heredity.
- Lesson Plan Submission: Participants were required to submit two lesson plans, demonstrating their ability to incorporate the content and pedagogical strategies from the OER.
- Reflective Writing: Each participant wrote a reflective piece based on their experience with the module, focusing on how it informed their teaching practices.
- Peer Assessments: Using the VLE workshop feature, participants provided peer assessments of each other's lesson plans and reflective writing.
- Video Lesson Uploads: Participants were also required to upload a video lesson showcasing their application of the content in a teaching setting.

DATA ANALYSIS AND FINDINGS

The data analysis focused on three key areas: learners, content, and teaching and learning.

- Lesson Plan and Reflection Analysis: The submitted lesson plans and reflective pieces were evaluated using rubrics that addressed the aforementioned key areas. A thematic analysis was performed to extract qualitative insights regarding the impact of the OER on participants' pedagogical approaches.
- Pre-test and Post-test Data: Pre- and post-test results were analyzed using factor analysis to assess changes in participants' knowledge and understanding of genetics

and heredity. This helped determine the effectiveness of the OER module in enhancing teaching, learning, and assessment practices.

Assessment completion rate

The data in Table 1 shows that all participants completed key assessments, with the exception of one who did not submit a session plan. Specifically, all 38 participants completed the pre-test, reflections, and post-test, while 37 participants submitted session plans (Table 1).

Table 1: Teachers' assessment completion rate

Area	Teachers	Total
Pre test	38	38
Session plans	37	37
Reflection	38	38
Post tests	38	38

Time spent on the course platform

Teachers were expected to spend a total of 30 hours to complete the module, with a weekly commitment of 5 hours. According to the data, 2 teachers spent less than 5 hours on the tasks, despite several reminders. Eleven teachers spent between 5 and 10 hours**, while** 22 teachers dedicated 10 to 20 hours. Additionally, 3 teachers spent between 21 and 30 hours to complete all the tasks prescribed in the module (Table 2). It should be noted that teachers invested significant additional time in activities such as developing lesson plans, implementing them, recording videos for peer review, and writing reflection reports. These tasks were not tracked by the Learning Management System (Moodle).

Table 2: Time spent by teachers on Moodle platform

Hours spent	Teachers	Total
Less than 5	2	2
5 to 10	11	11
10 to 20	22	22
21 to 30	3	3
More than 30	0	0
Total:		**38**

Change from pre- and post- test

Average total score in pre-test: 59 %

Average total score in post-test: 56%

The percentage scores of the participants in the pre- and post-tests are presented in Table 3. During the pretest, 2 participants achieved the accomplished level, 31 reached the proficient level, and 5 was at the emerging level. The post-test results did not show a positive trend as there were none in accomplished level, proficient level dropped to 28 from 31 and there were also 3 candidates whose performance were in novice level.

Table 3: Comparison of Teachers' Pre-Test and Post-Test Performance Levels Across Proficiency Categories

Pretest/posttest	Posttest: Novice (0-25%)	Posttest: Novice (26-50%)	Posttest: Novice (51-75%)	Posttest: Novice (76-100%)
Pretest: Novice (0-25%)				
Pretest: Emerging (26-50%)	1	1	3	
Pretest: Proficient (51-75%)	2	6	23	
Pretest: Accomplished (76-100%)			2	

Detailed Insights from Pre- and Post-Test Data Analysis

The analysis of the pretest and posttest data indicates that the OER module on Genetics and Heredity had a mixed impact on the targeted competencies. While the intervention was successful in some areas of the targeted competencies, its overall effectiveness varied. Notably, the module significantly enhanced participants' ability to evaluate resources for diverse content representations. This positive outcome is corroborated by other data sources such as classroom observations, lesson plans development, and reflections, which collectively indicate a beneficial effect on professional development. Analysis of pretest and posttest data reveals notable differences in average mean scores and standard deviations, reflecting changes in understanding and proficiency. Detailed examination of the data highlights both progress and opportunities for further development in participants' skills following the intervention. Tables 4, 5, and 6 provide a comprehensive summary of the data, including descriptive statistics, changes in mean scores, standard deviations, and effect sizes, offering a clear representation of the intervention's impact.

In Theme K1.2, while there was a slight decrease in the ability to recognize participants' prior conceptions and misconceptions, this change points to the potential for refining instructional strategies to better address this critical skill. The increase in standard deviation suggests that some participants made strides, indicating variability that can be harnessed for targeted support.

In Theme K1.3, the data reveals a positive trend with a modest improvement in recognizing areas of difficulty that participants face, reflected in the increase from a pretest mean of 0.464 (SD = 0.406) to a posttest mean of 0.526 (SD = 0.416) (Table 4). This progress underscores the impact of effective strategies provided during the training, which helped participants better understand and identify student challenges.

Theme K2.1 shows a small yet meaningful improvement in understanding the nature of science, with the mean score increasing slightly from 0.754 (SD = 0.426) to 0.768 (SD = 0.42) (Table

4). This suggests that the intervention (e.g. workshop) was successful in enhancing participants' insights into this fundamental aspect of teaching, though the progress was modest.

Although Theme K2.2 saw a slight decrease in the ability to identify big ideas, key concepts, and theories, the overall strong baseline score suggests that participants already had a solid foundation in this area. The data provides an opportunity to explore new ways to reinforce these concepts during future training sessions. Similarly, the small decline in Theme K2.3, where participants' ability to explain the goals of teaching the subject decreased, indicates an area where more focused intervention can lead to meaningful improvements.

In Theme K2.4, while there was a slight reduction in the ability to sequence and connect concepts within subjects and across grades, this finding highlights an opportunity to strengthen participants' understanding of how to effectively organize and relate concepts across different educational levels.

The ability to evaluate resources for multiple forms of representing content (Theme K3.1) saw a minor decrease, yet this indicates the importance of continuing to explore diverse educational resources and finding ways to boost confidence and skills in this area. Similarly, in Theme K3.2, the slight decline in selecting instructional strategies to support multiple forms of participants' engagement points to the value of providing additional practical examples and strategies that can be immediately applied in the classroom.

Finally, in Theme K3.3, although there was a notable decrease in the ability to choose multiple tools of assessment to encourage multiple modes of expression, this significant change presents a clear direction for future focus. By addressing this area with targeted interventions, there is a strong potential to elevate participants' competence in utilizing diverse assessment tools, ultimately enhancing the learning experience.

Overall, these findings offer a valuable roadmap for continuous improvement, with clear indicators of where further support and development can yield positive outcomes in participants' teaching practices.

Table 4: Summary of Pretest and Posttest Scores by Themes

Theme	Measure	N	Mean	SD	Change
K1.2 Recognize Students' Prior Conceptions and Misconceptions	Pretest	38	0.676	0.42	-0.076
	Posttest	38	0.60	0.438	
K1.3 Recognize Areas of Difficulty That Students Face	Pretest	38	0.464	0.406	+0.062
	Posttest	38	0.526	0.416	
K2.1 Understand Nature of Science	Pretest	38	0.754	0.426	+0.014
	Posttest	38	0.768	0.42	
K2.2 Identify ‘Big’ Ideas, Key Concepts, and Theories	Pretest	38	0.806	0.284	-0.048
	Posttest	38	0.758	0.322	
K2.3 Explain Goals of Teaching the Subject	Pretest	38	0.316	0.432	-0.038
	Posttest	38	0.278	0.418	

Theme	Measure	N	Mean	SD	Change
K2.4 Sequence and Connect Between Concepts	Pretest	38	0.428	0.386	-0.048
	Posttest	38	0.380	0.358	
K3.1 Evaluate Resources for Multiple Forms of Content	Pretest	38	0.590	0.418	-0.046
	Posttest	38	0.544	0.470	
K3.2 Select Instructional Strategies for Student Engagement	Pretest	38	0.442	0.396	-0.038
	Posttest	38	0.404	0.430	
K3.3 Choose Multiple Tools of Assessment	Pretest	38	0.868	0.308	-0.324
	Posttest	38	0.544	0.470	

Note: SD = Standard Deviation.

The descriptive statistics in Table 5 offer insightful details on the participants' pretest and posttest performance across various themes, highlighting areas of growth and valuable directions for future focus.

Table 5: Descriptive Statistics for Pretest and Posttest Scores

Theme	Pretest Mean	Pretest SD	Posttest Mean	Posttest SD	Mean Change	SD Change
K1.2 Recognize Students' Prior Conceptions and Misconceptions	0.676	0.42	0.600	0.438	-0.076	0.18
K1.3 Recognize Areas of Difficulty That Students Face	0.464	0.406	0.526	0.416	+0.062	0.08
K2.1 Understand Nature of Science	0.754	0.426	0.768	0.42	+0.014	0.12
K2.2 Identify 'Big' Ideas, Key Concepts, and Theories	0.806	0.284	0.758	0.322	-0.048	0.06
K2.3 Explain Goals of Teaching the Subject	0.316	0.432	0.278	0.418	-0.038	0.10
K2.4 Sequence and Connect Between Concepts	0.428	0.386	0.380	0.358	-0.048	0.03
K3.1 Evaluate Resources for Multiple Forms of Content	0.590	0.418	0.544	0.470	-0.046	0.05
K3.2 Select Instructional Strategies for Student Engagement	0.442	0.396	0.404	0.430	-0.038	0.03
K3.3 Choose Multiple Tools of Assessment	0.868	0.308	0.544	0.470	-0.324	0.16

Note: SD Change = Standard Deviation of Change.

For Theme K1.3, which pertains to recognizing areas of difficulty that students face, the data shows a positive mean change from 0.464 (SD = 0.406) in the pretest to 0.526 (SD = 0.416) in the posttest. This improvement, along with a small increase in the standard deviation, suggests that participants made progress in identifying student challenges, with some variation in how different individuals benefited from the intervention.

In Theme K2.1, focused on understanding the nature of science, there is a slight increase in the mean score from 0.754 (SD = 0.426) to 0.768 (SD = 0.42). This positive change, accompanied by a small reduction in the standard deviation, indicates that participants not only improved their understanding but also became more consistent in their knowledge of this critical subject.

Although some themes, such as K2.2 (identifying big ideas, key concepts, and theories) and K3.1 (evaluating resources for multiple forms of content), show slight decreases in mean scores, the changes in standard deviation are minimal. These findings suggest that while there may be areas for improvement, the participants maintained a relatively consistent level of understanding, which can be further enhanced through targeted support.

The most significant area for potential growth is in Theme K3.3, which involves choosing multiple tools of assessment. The data shows a decrease in the mean score from 0.868 (SD = 0.308) to 0.544 (SD = 0.470), coupled with an increase in the standard deviation. This indicates that while some participants may have struggled with this concept, there is a clear opportunity to focus on enhancing their ability to utilize diverse assessment tools effectively.

Overall, the descriptive statistics reflect both the progress participants have made and the opportunities that exist for further development. The small changes in both mean scores and standard deviations across most themes highlight the potential for continued growth, with the data providing a valuable guide for refining future interventions to support participants in their professional journey.

The analysis presented in Table 6 highlights areas of both progress and valuable opportunities for growth in participants' understanding and skills. While the effect sizes are generally small, the data reflects meaningful insights that can guide future improvements.

For instance, Theme K1.3, which focuses on recognizing areas of difficulty that students face, shows a positive change, with the posttest mean increasing from 0.464 to 0.526 (Table 6). Although the effect size is small, this indicates that participants made progress in this area, suggesting that the intervention helped enhance their ability to identify student challenges.

Similarly, in Theme K2.1, which addresses understanding the nature of science, there is a slight increase in the mean score from 0.754 to 0.768 (Table 6). This small but positive shift indicates that participants gained some additional insight into this essential concept, reflecting the effectiveness of the workshop content in reinforcing their understanding.

While some themes, such as K2.2 (identifying big ideas, key concepts, and theories) and K3.1 (evaluating resources for multiple forms of content), show slight decreases in mean scores, the small effect sizes suggest that these areas remain well within reach for further improvement. The decreases offer valuable feedback on where the training can be refined to better meet participants' needs.

The most notable area for growth is in Theme K3.3, which involves choosing multiple tools of assessment. Although there was a medium effect size with a decrease in the mean score, this highlights a clear opportunity for targeted intervention. By focusing on this area in future

training, participants can be better equipped to use diverse assessment tools, ultimately leading to more effective and inclusive teaching practices.

Table 6: Change in Mean Scores across themes

Theme	Pretest Mean	Posttest Mean	Change	Effect Size
K1.2 Recognize Students' Prior Conceptions and Misconceptions	0.676	0.600	-0.076	Small
K1.3 Recognize Areas of Difficulty That Students Face	0.464	0.526	+0.062	Small
K2.1 Understand Nature of Science	0.754	0.768	+0.014	Small
K2.2 Identify 'Big' Ideas, Key Concepts, and Theories	0.806	0.758	-0.048	Small
K2.3 Explain Goals of Teaching the Subject	0.316	0.278	-0.038	Small
K2.4 Sequence and Connect Between Concepts	0.428	0.380	-0.048	Small
K3.1 Evaluate Resources for Multiple Forms of Content	0.590	0.544	-0.046	Small
K3.2 Select Instructional Strategies for Student Engagement	0.442	0.404	-0.038	Small
K3.3 Choose Multiple Tools of Assessment	0.868	0.544	-0.324	Medium

Note: Effect Size is categorized based on Cohen's d

Overall, the analysis provides a constructive framework for ongoing development. The small changes in mean scores across most themes indicate that participants are building on their existing knowledge and skills, and with continued support, they have the potential to make even more significant strides in their professional growth.

Analysis of Pedagogical Content Knowledge (PCK) and Community of Practice (CoP)

a. Learners

In promoting inclusion and equity within the classroom, the participants' lessons demonstrated a strong commitment to creating engaging opportunities for all students. These opportunities were facilitated through a variety of interactive activities and collaborative group work, ensuring that every student had the chance to actively participate. Several lessons began by asking questions designed to connect with students' existing knowledge and experiences, thereby tapping into their prior conceptions. This approach not only helped in engaging students from the start but also made the learning process more relevant to their everyday lives. Moreover, some lessons effectively addressed common misconceptions by actively exploring students' preconceptions. This was achieved through the use of multimedia resources, such as videos, and real-life examples that provided concrete contexts for understanding abstract concepts. These strategies helped clarify misunderstandings and reinforced accurate knowledge, further supporting an inclusive and equitable learning environment.

Participant 5000 "I tried to encourage the slower groups to do their work faster by asking all the groups to announce "Bingo," as they completed their work".

Participant 5004 "Creating a safe and inclusive space was beneficial. By recognizing signs of anxiety or low participation, I provided support through encouragement, reassurance, and

positive reinforcement. This not only boosted confidence but also reduced learner stress through flexible learning options and accommodations".

Participant 5006 "To address any potential emotional stress and ensure a supportive learning environment, I provided ample time for the students to finish their assigned tasks. This approach helped maintain a relaxed and productive atmosphere throughout the lesson".

Participant 5014 "Provided help in the form of scaffolding, reinforcement and clarification. Instructed well to not stress out a lot before the onset of the activity".

Participant 5022 "Some children are very introverted and never open up when asked questions. Although I tried my best to include them, it was difficult. Those children who are less exposed to the outside world are supposed to be introvert".

Participant 5033 "Students were not placed like in a typical classroom setting. The activities were all individual though a discussion or two were taking place informally.

-student providing wrong answers were quite anxious, however, they were not directly pointed out as wrong but rather later explanation was provided".

b. Content

Several participants' lessons effectively promoted higher-order thinking by incorporating critical and thought-provoking questions throughout the instruction. These questions encouraged students to go beyond mere memorization and engage in deeper analysis, synthesis, and evaluation of the material. By challenging students to think critically, the lessons fostered an environment where learners could explore complex ideas, consider diverse perspectives, and develop well-reasoned arguments.

In addition to open-ended questions, participants also utilized multiple-choice questions to assess students' understanding and promote active engagement with the content. These questions were strategically integrated into activities and discussions, providing opportunities for students to apply their knowledge, analyze different options, and justify their choices. This combination of questioning techniques helped to create a dynamic learning environment where students could develop critical thinking skills and deepen their comprehension of the subject matter.

Participant 5006 "I made sure to cover all essential lesson components, including recapitulation, introduction, development, and closure, by integrating the design thinking approach. This approach not only structured the lesson effectively but also encouraged creativity and critical thinking among the learners".

Participant 5005 "during a debate on why siblings can look different, students applied their knowledge to argue based on evidence and reasoning. These activities promoted critical thinking and reinforced scientific inquiry, illustrating core scientific practices in a practical and engaging manner".

Participant 5022 "Students were asked to spell the answers after the activity. Provided feedback".

Participant 5030 "I did pre-test and post-test using google form. Compared to the pre-test many misconceptions were done away with. Basic questioning at the end session also revealed that they understood the relationship between three genetic entities".

Participant 5030 "different students had different answers regarding the location of chromosomes, DNA and genes. Students did not really know their relationship until after their group work".

c. Teaching and Learning

Through various modes of expression, including the use of technology, worksheets, textbooks, and visual aids like pictures. By integrating these different resources, the lessons catered to various learning styles, allowing students to engage with the content in a manner that best suited their preferences and needs. For instance, technology was often employed to create interactive and multimedia-rich experiences, while worksheets and textbooks provided structured, text-based learning opportunities. Visual aids, such as pictures, further supported learning by offering visual representations of key concepts.

In addition to these resources, some teachers creatively incorporated locally available materials to construct models, making abstract concepts more tangible and easier to grasp. This hands-on approach not only made the lessons more engaging but also encouraged students to use their imagination and creativity.

Participant 5000 "Children were allowed to use phones in the group at the beginning of the lesson to guess the structure of chromosomes. Children used the app Mentimeter to answer the MCQ. Online video was used to supplement the lesson and also use multiple media to impart information to the children. Flashcards were used to show answers so that children could not only hear the answers but also see them and could easily carry out assessments of group work. A worksheet (to label the different parts of a chromosome) was used after the topic on the structure of chromosomes to help children assess their learning by recalling what they have learned in class".

Participant 5005 "I utilized a variety of resources, including modeling clay in different colors, chart papers, markers, Xerox paper, a projector, a laptop, a whiteboard, and board markers. These resources effectively met the needs of the learners as intended".

Participant 5006 "Throughout the lesson, I utilized a range of teaching aids including a whiteboard, markers, paper, projector, PowerPoint presentation, a video clip, laptop, and a speaker. These resources helped to enhance student engagement and understanding of complex concepts in genetic engineering and recombinant DNA technology".

Participant 5014 "This integration of visualization through videos and hands-on activity facilitated a comprehensive exploration of the intricate relationship among chromosomes, DNA and genes".

Participant 5033 "Nearpod was used for the class. The class was engaging as most of the lesson was student-based activity. Because of nearpod all the students' responses were available and therefore it was easier to understand where students' understanding on the topic lies".

The Figure 1 below presents the mean scores of Bhutanese biology teachers on four key categories of Pedagogical Content Knowledge (PCK): learners, content, teaching and learning. These categories represent the teachers' understanding of their students, subject matter, and ability to design effective teaching strategies. The results suggest that while teachers are skilled in creating a conducive learning environment, there is potential for further development in their overall PCK (Figure 1).

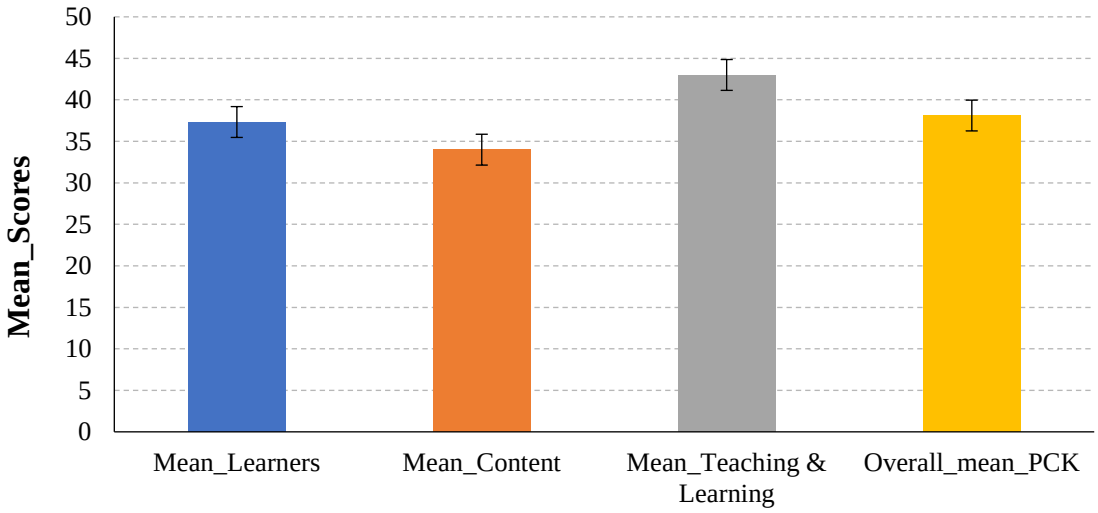

Figure 1: Mean scores of biology teacher participants on Pedagogical Content Knowledge (PCK) across Key Teaching Categories

The table 7 below depicts scores based on the presence and appropriateness of instructional practices, using a scoring system where Absent=0, Present but Inappropriate=1, and Present and Appropriate=2. Mean scores and standard deviations indicate the effectiveness of the strategies employed by participants across various categories.

The analysis of biology teacher participants' Pedagogical Content Knowledge (PCK) reveals a generally solid grasp of key teaching practices, with mean scores indicating a presence of pedagogical strategies across various themes. The highest mean score, 1.75, was recorded in the category "Understanding Nature of Science," suggesting that participants effectively apply appropriate PCK in this area. Additionally, a mean score of 1.54 in "Evaluating Educational Resources" indicates a favorable grasp of resource evaluation. However, the data also highlight critical areas for improvement, particularly in "Promoting Inclusion and Equity," "Building on Prior Conceptions," and "Addressing Misconceptions," which all recorded lower mean scores around 1.19 to 1.24 (Table 7). These findings imply that while strategies may be present, they often lack effectiveness, indicating the need for targeted professional development. The moderate standard deviations across the categories suggest variability in responses, with some teachers facing greater challenges in specific aspects of PCK. Overall, the analysis underscores the importance of ongoing support and training to enhance teachers' effectiveness in delivering inclusive and impactful biology education.

Table 7: Assessment of biology teacher participants Pedagogical Content Knowledge (PCK) across key teaching categories and themes (n=38).

Category	Theme	Total mark (76)	Mean	SD
a. Learners	P1.1 Promote inclusion and equity	44	1.16	0.49
	P1.2 Build on students' prior conceptions	42	1.11	0.51
	P 1.3 Address misconceptions and areas of difficulties	24	0.63	0.54

Category	Theme	Total mark (76)	Mean	SD
b. Content	P2.1 Use processes on science and mathematics	30	0.79	0.66
	P2.2 Facilitate higher order thinking	41	1.08	0.75
	P2.3 Plan to build students' competences to meet the goals of teaching science/ mathematics	31	0.82	0.51
c. Teaching and Learning	P3.1 Use instructional strategies for active learning	54	1.42	0.60
	P3.2 Use multiple representations of content	54	1.42	0.64
	P3.3 Create opportunities for multiple modes of expression	51	1.34	0.53
	P3.4 Use locally available materials	27	0.75	0.77
	P3.5 Link conceptual content to students' everyday life experiences and prior knowledge	29	0.78	0.58

SD: Standard Deviation

Social learning in Community of Practices

a. Frequency of posts: Table 8 illustrates the frequency of posts by participants, revealing that a total of 498 posts were made, with 401 posts (approximately 80.5%) contributed by teacher participants and 97 posts **(**about 19.5%**)** from teacher educators (Table 8). This significant disparity indicates that teacher participants were markedly more engaged in the discussions or activities, suggesting a higher level of interaction and investment in the module. In contrast, the lower posting frequency of teacher educators may reflect their role as facilitators or observers rather than active contributors. Overall, these findings highlight the need for strategies to encourage more balanced participation among all roles in future engagements.

Table 8: Frequency of posts by participants

Role	Number of posts	Percentage
Teacher participants	401	80.52%
Teacher Educators	97	19.48%
Total	**498**	**100%**

b. Frequency of posts by content: The data in Table 9a shows that the majority of posts (74.7%) were related to communication and administrative matters, with 372 out of 498 total posts. Technical posts accounted for 20.28% (101 posts), while posts related to

Pedagogical Content Knowledge (PCK) and Universal Design for Learning (UDL) were notably lower, comprising only 3.01% (15 posts) and 2.01% (10 posts), respectively. This indicates a strong focus on administrative communication, with limited engagement in discussions around instructional strategies and inclusive teaching practices.

Table 9a: Frequency of posts by content

Type of Posts	Number of posts	Percentage
PCK	15	3.01%
UDL	10	2.01%
Technical	101	20.28%
Communication/ Administrative	372	74.7%
Total	**498**	**100%**

c. Frequency of post by type: Table 9b shows that the majority of posts were text-based, accounting for 90.36% (450 posts) of the total 498 posts. Images made up 9.04% (45 posts), while external links to other resources were rarely used, with just 1 post (0.2%). Other post types, such as voice recordings, were similarly minimal, with only 2 posts (0.4%). This indicates a strong preference for text-only communication among participants.

Table 9b: Frequency of posts by type

Type of post	Number of posts	Percentage
Text only	450	90.36%
Images	45	9.04%
External Links to other resources	1	0.2%
Others (voice)	2	0.4%
Total	**498**	**100%**

d. Qualitative dialogues/ discussion threads: Teacher engagement in the Community of Practice (CoP) has been highly dynamic, characterized by active two-way interactions. Discussions have covered a wide range of important topics, such as pedagogical content knowledge (PCK), responding to peer inquiries, sharing and discussing classroom practices, promoting inclusion, and showcasing student work. These interactions reflect the vibrant nature of the CoP and demonstrate the meaningful exchange of ideas among participants.

e. Surprises: There was a drop from pretest to post-test (6%) in the performance of the participants which was not expected. However, the participants seem to have good

content knowledge as revealed through their lesson plan and reflection. The other possible reason for the no impact seen in the posttest also could be, since it was the first attempt to curate an OER by the Biology academics of SCE with thorough deliberation in the team it was decided that the first module will be an introduction, so that it leaves us with opportunity to curate second advanced module in future, therefore, only the basics of genetics and hereditary concepts are included in this module consequently it has enabled participants to comprehend and contextualise the learning well in their lesson plans.

f. Any changes required in the module design: Need to add advanced level content as well since the module focused only on the basic level; Pretest post test questions must be aligned to the content of the module. Further, the timeline for the implementation also needs to be studied.

CONCLUSION

This study provides a comprehensive examination of the teaching competencies and pedagogical practices among biology teachers in relation to their knowledge of genetics and heredity. The analysis of pre- and post-test data revealed a concerning decline in overall performance, emphasizing the necessity for targeted interventions to enhance understanding and application of assessment strategies. While there were positive shifts in some areas, particularly in recognizing student difficulties and understanding the nature of science, the mixed results suggest that sustained professional development is essential for fostering deeper pedagogical content knowledge.

Further, the insights gained from the thematic analysis of participants' reflections underscore a strong commitment to promoting inclusion and equity within the classroom. Teachers actively engaged in collaborative group work and utilized a variety of resources, including technology and multimedia, to support diverse learning styles. However, challenges remained, particularly in addressing misconceptions and reaching introverted students, highlighting the need for ongoing support in these areas. The examination of social learning within Communities of Practice revealed vibrant engagement among participants, albeit with a predominant focus on administrative communication rather than instructional strategies. This indicates a potential area for growth, as fostering discussions centered on pedagogical practices could further enhance the sharing of innovative teaching approaches.

Despite the unexpected drop in performance from pre-test to post-test, the strong content knowledge demonstrated in lesson plans suggests that participants are well-equipped for future advancements in biology education. As the curriculum evolves, there is an opportunity to incorporate more advanced content and better align assessments with instructional objectives.

In conclusion, the findings of this study highlight the importance of continuous professional development, targeted training, and collaborative dialogue among educators to improve teaching practices and enhance student learning outcomes in biology education. Moving forward, these insights serve as a valuable foundation for future curriculum design and the establishment of effective pedagogical strategies that promote inclusive and impactful learning experiences.

DISCLAIMERS

The views expressed herein do not necessarily represent those of International Development Research Centre (IDRC) or its Board of Governors.

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