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Biology Teachers' Systems Thinking Practices and Students' 21st Century Skills: Bases for A Professional Development Model

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ABSTRACT

This study investigated biology teachers' systems thinking (ST) practices and their implication on developing students' 21st Century Skills (21CS) to determine a professional development model. An iterative concurrent mixed-method design was employed, incorporated qualitative and quantitative methods across multiple stages. Participants were secondary teachers enrolled in innovative graduate school classes. Systems thinking practices were based on the Philippine Professional Standards for Teachers (PPST). Findings indicate that the Systems Thinking Professional Development Course (STPDC) significantly improved teachers' practices across four PPST domains. Five biology teachers implemented systems thinking lessons, revealing a significant positive impact on the students' critical thinking and problem-solving skills, information literacy, and communication skills. Based on these results, the 5As professional development model was developed: *Acquire*, *Apply*, *Assess*, *Adapt*, and *Aspire*. The study recommends the STPDC for biology teachers to enhance their holistic understanding of biological phenomena and foster students' 21st-century skills development.

Keywords: ***systems thinking, professional development, biology teachers, 21st century skills***

Introduction

Biology education transformed into an interdisciplinary, system-oriented, and integrative approach. It allows us to understand nature as a system rather than parts and gives a holistic view of a phenomenon. A holistic perspective on biological phenomena is essential among students and it could be developed through systems thinking (ST). As science curricula in the United States, Netherlands, and Germany, helps students understand complex environmental issues in response to sustainable development (Mambrey et al., 2020). This study builds on these examples by exploring how ST can be applied within the Philippine context, particularly in secondary biology education. ST in biology education is grounded on General System Theory (GST), cybernetics, and dynamic systems theories. Verhoeff (2003) articulated that GST conceptualizes an open-system relationship between living organisms and the environment. The energy and information were exchanged within a boundary in a hierarchal order. Cybernetics is concerned with patterns, regulation, and feedback in living systems that occur in a non-linear manner (Ashby, 1957). The dynamic systems theories view living systems as self-organizing which can form new patterns in behavior and development, leading to emergent characteristics non-linearly (Thelen & Smith, 2012). These theories provide a grounding framework for the characteristics of ST applied in biology. Verhoeff et al. (2018) discussed the importance of integrating the three systems theories' key concepts and considering the conceptual development and epistemological nature of system thinking.

The practical implications of this theoretical approach are demonstrated in several studies. Yoon et al. (2018) investigated research from 1995 to 2015 on teaching and learning complex systems in science education. The framework of complex systems characteristics -structure, process, and state,aligns with these three theories. Nehm (2019) states the need to develop a theoretical or conceptual framework to help students make sense of their living systems. Gilissen et al. (2021) supports the need to development a theoretical framework in a study using a structured systems model and scaffolding questions helped the students visualize and explain biological phenomena from systems perspectives. Moore-Anderson (2021) recommended using ST in curriculum design and assessment through the pragmatic framework he presented on measuring mechanistic reasoning. He mentioned that systems thinking may require complex pedagogy and regular exposure to help teachers and learners explain and organize biological knowledge in meaningfully integrated mechanisms. For instance, Wilson et al. (2020) developed modeling in the classroom as a teaching guide to support ST skills in understanding biology. They used it as a formative and summative assessment where students can demonstrate higher-order thinking skills by interpreting, using, and building models. It was emphasized in their study that using modeling in instruction requires time for planning and practice for effective instruction and activities. Similarly, Gilissen et al. (2020) developed design guidelines for the implementation of ST using a lesson study approach. Based on their result, there is a need to introduce the systems characteristics and systems language explicitly to be applied in different contexts. This was also found to develop students' metacognitive skills.

Concerning the Philippine science curriculum, it aims to integrate science concepts across disciplines to address social, health, and environmental issues (Department of Education, 2016). However, teaching biological concepts is often separated into topics, leading to rote memorization. Using the ST approach in teaching biology may provide a meaningful conceptualization of biological processes, allowing students to understand, analyze, and synthesize problems. System thinking determines the components in the system, its interaction, and its direct and indirect effects in a dynamic approach to understanding biological processes and problems (Mambrey et al., 2020). This approach may also help address real-life issues concerning sustainable development. Students' reasoning skills and critical thinking are developed by determining the interactions of elements in a system and processes involved at different hierarchal levels (Gilissen et al., 2021). Furthermore, ST may provide authentic learning and assessment as students create different conceptions and representations to explain their system model.

However, developing students' system thinking skills depends on the extent of knowledge and competencies of teachers to design learning materials and execute strategies to build system thinking (Streiling et al., 2021). Teachers should be able to plan and implement learning materials and strategies effectively and efficiently to develop scientific literacy and 21st-century skills (21CS) among students. Ritchie (2017) revealed that continued learning and practice with ST skills may positively impact on students' 21CS. The students may demonstrate a deeper understanding of complex natural phenomena by expressing their answers through response questions, systems diagrams, and verbal assessments.

In this regard, the teacher needs professional development (PD) training or courses executing a teaching strategy (Sakib & Obra, 2019). Being able to develop PD for teachers supports their upskilling and reskilling for teaching 21st-century learners. Equipping the teachers with relevant content and pedagogical knowledge may also develop their confidence in teaching the subject matter. In terms of the integration of ST in biology lessons, Gilissen et al. (2020) revealed that ST is not yet fully implemented in biology lessons. It was recommended to be explicitly taught in the class regarding systems language and characteristics.

There are also limited studies about teachers' knowledge and use of the ST approach. Most of the research on ST was focused on facilitating it among students (Gilissen et al., 2020); Hmelo-Silver et al., 2017; Mambrey et al., 2020; Rustaman, 2021; Yoon et al, 2018; York et al., 2019). Ritchie (2017) suggested creating discipline-based and grade-level specific training to increase teachers' self-efficacy in using ST. The findings indicated that teachers find ST a helpful strategy to promote deeper learning and comprehend biological phenomena. Additionally, the development of ST abilities and 21CS would result from the teachers' capacity to incorporate cross-cutting concepts in biology lessons. According to Schoen and Fusarelli (2008 cited in Ritchie, 2017), "Systems thinking helps build the 21st-century skills that the teachers aim to instill in their learners." In this view, teachers should be able to use complex systems as teaching and learning 21st-century educational standards. There is a need to promote ST among teachers to prepare them for teaching biology lessons coherently and holistically.

Accordingly, Pineda et. al (2022) examined biology teachers' ST practices the four dimensions of the Philippine Professional Standards for Teachers (PPST) to support students' 21CS development and help them think holistically about biological phenomena. The four PPST domains – content knowledge and pedagogy, learning environment, curriculum and planning, and assessment and reporting – were used to evaluate the ST practices. This study focuses on investigating the potential effects of ST practices in teachers' activities on students' 21CS growth.

This study aims to investigate the extent of ST practices of secondary biology teachers and their implication to the development of students' 21st-century skills in learning complex real-life biological phenomena. Specifically, it sought to answer the following questions:

1. Does a Systems Thinking Professional Development Course (STPDC) improve teachers' systems thinking teaching practices in terms of:
   a. Content Knowledge and Pedagogy;
   b. Learning Environment;
   c. Curriculum and Planning; and
   d. Assessment and Reporting?
2. What are the implications of systems thinking practices of proficient biology teachers on students' 21st-century skills in terms of:
   a. Information, media, and technology;
   b. Learning and Innovation;
   c. Communication; and
   d. Life and career skills?
3. What professional development model could be developed based on biology teachers' systems thinking practices and students' 21st-century skills?

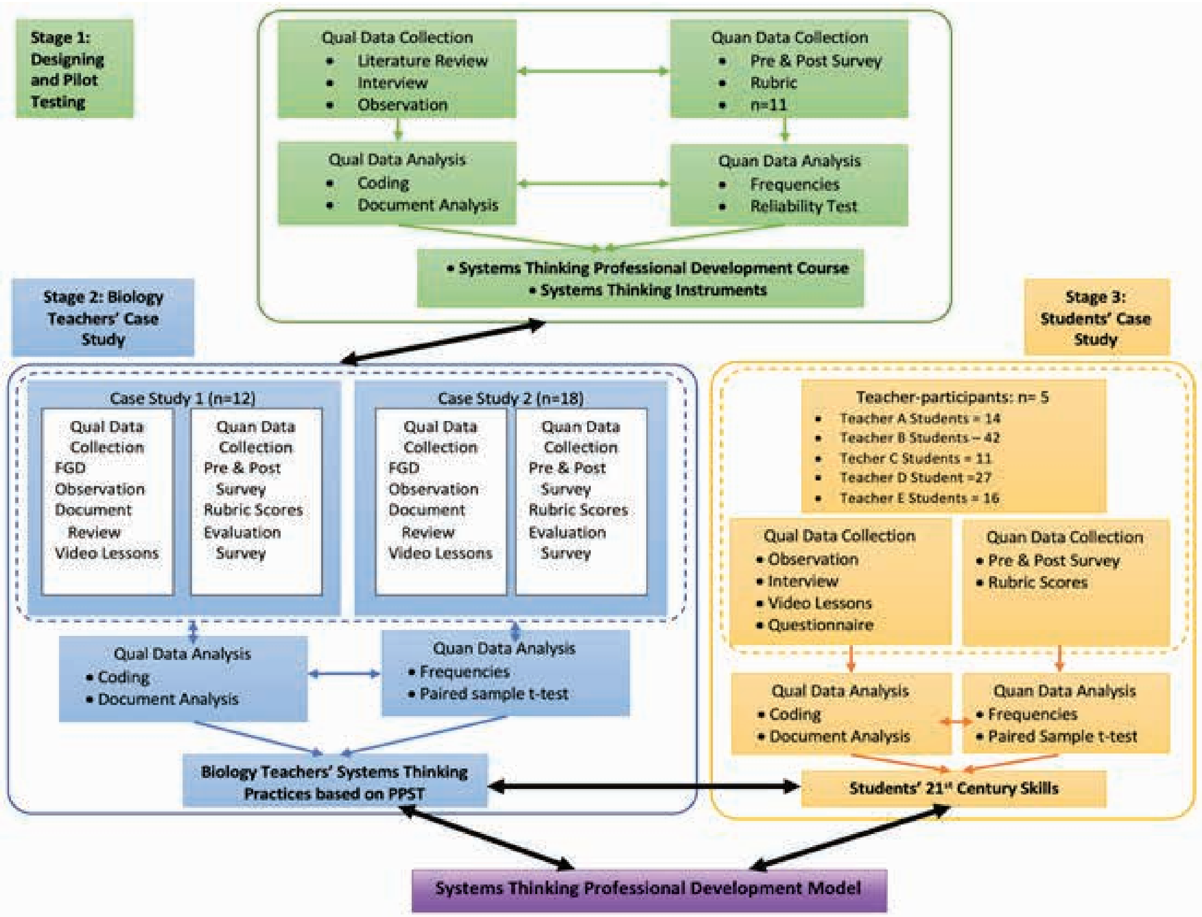
Methods

Research Design

An iterative concurrent mixed-method research design was used to develop a professional development (PD) model in the ST approach based on the teachers' practices in biology lessons and their implications for students' 21st-century skills (21CS) as shown in Figure 1. This involved three or more steps in data collection and analysis, each informing the next.

Figure 1

Iterative Concurrent Mixed Method Research Design for Biology Teachers' Systems Thinking Practices and Students' 21st-century Skills Toward a Professional Development Model



Qualitative and quantitative data are collected, allowing the researcher to collect and analyze data repeatedly to build, refine, and improve the output of the study. Both data provide an in-depth understanding of the implications of the teachers' ST teaching practices among students' 21CS. The research design is a cyclical process that produces thoroughly analyzed data, resulting in the emerging professional development model on systems thinking (Pulla, 2016).

Participants

The purposive sampling method was used. There were two types of participants: teachers and students. The teacher-participants were currently enrolled in the innovative class of Graduate School under the program Master of Arts in Teaching (MAT) major in Science; had been teaching Science in Junior High School for at least three years; and were familiar with the Most Essential Learning Competencies for the Philippine Science Curriculum. The pilot study for the innovative class on ST approach was conducted during the Second Semester of School Year 2021-2022. Eleven science teachers volunteered to participate in the study as they enrolled in the courses for innovative classes. All the teacher-participants were in the public secondary high school and were Teacher 1 based on their academic rank. The profile of the teacher-participants is shown in Table 1.

Table 1

Profile of Teacher-Participants for the PD course on Systems Thinking

Profile	2nd Semester S.Y. 2021-2022 (Pilot study) N=11	Summer S.Y. 2021-2022 (Case study 1) N=12	1st Semester S.Y. 2022-2021 (Case study 2) N=18
Sex			
a. Male	3	1	5
b. Female	8	11	13
No of years of teaching			
a. 1-5 years	7	6	8
b. 6-10 years	3	3	5
c. 11-15 years	1	3	3
d. 16-20 years	0	0	2
Bachelor degree major			
a. Biology	7	8	10
b. Chemistry	2	0	2
c. Physics	2	0	2
d. General Science	0	4	4

The next group of participants was the students of the teacher-participants who volunteered and were approved to participate in the implementation of their developed lesson exemplars on ST. The case studies differ in three aspects: school, teacher, and students. Table 2 shows the student participants involved in the case studies.

Table 2

Profile of Student-Participants of the Teachers Implementing Systems Thinking Lessons

Teacher	Division	School	Grade Level	Student-Participants					
				Age			Male	Female	Total Number
				12-13	14-15	16-17			
A	Rizal	Public HS	7	14	0	0	5	9	14
B	Rizal	Public HS	8	30	12	0	21	21	42
C	Rizal	Public HS	9	0	11	0	7	4	11
D	Pasig City	Public HS	10	0	16	11	15	12	27
E	Quezon City	Public HS	10	0	6	10	8	8	16

The affiliated schools of the teacher-participants were used as were used as a case study for implementing the ST lesson exemplar. The teacher participants were all teaching science in public high schools: one from Quezon City, one from Pasig City, and three from Rizal province. There were 110 student-participants from different schools. The sections were heterogeneous. The students who completely answered the given survey forms were considered and included in the study.

Instruments

Several instruments were used to measure the ST practices of teachers. The Biology Systems Thinking Questionnaire, interview guides, rubrics for learning outputs, lesson exemplars, and video lesson demonstrations were developed to assess the ST practices of the teachers based on the four domains of PPST. The research instruments had undergone content validation by two biology major professors, one educational research professor, one DepEd Education Specialist in Science, and one language expert professor. The students' perceived 21CS Inventory, observation checklist, and interview guides were used to determine the implication of the ST approach on students' 21CS development. Lastly, evaluation forms on the course sessions and modules were developed to determine the perception of the teacher-participants on the developed PD of the ST approach in Biology. These research instruments have been validated by a biology major expert, one educational management professor, and two language expert professors.

Procedures

This study encompasses several stages in determining the PD model for ST. The first stage aimed to identify the ST characteristics through an intensive systematic literature review of theories and studies. The Philippine Professional Standards for Teachers (Department of Education, 2017), Philippine Science Curriculum Framework (Department of Education, 2016), and Philippine 21CS framework and lesson exemplars (Department of Education, 2019) aligned the identified ST characteristics with the Philippine context. Validation of ST practices, and pilot-testing using the STPDC were used. The STPDC was pilot-tested during the Second Semester of School Year 2021-2022, providing baseline data and insights. Data collection included iterative focus group discussions, observations, and interviews to test, reflect on, and revise the developed STPDC. After the session, participants evaluated the developed course. The researcher revised the initial course on ST based on participants' feedback, evaluation results, and their learning outputs.

The second stage used a multi-qualitative method, including focus group discussions, observations, document review, and video lessons ethnography. Quantitative data collection was also done by administering the Biology Systems Thinking Questionnaire (BSTQ) before and after the course. The ST skills of the teachers were evaluated using rubrics and document analysis. The case studies were implemented during the Summer Term of School Year 2021-2022 and the First Semester of School Year 2022-2023. The teacher-participants developed a lesson exemplar and video lesson for classroom implementation. Their developed lesson exemplar and video lesson using the ST approach were evaluated by their respective science department chairs and co-teachers. After the course, the researcher had a post-meeting interview with the participants to evaluate their teaching experience.

After the teacher-participants completed the STPDC, the third stage concentrated on understanding how teachers' practices relate to the ST approach and how this influences students' 21CS. Interviews, class observations, focus group discussions, and document reviews were used for qualitative data. Quantitative-descriptive data on the students' perceived 21CS and learning output rubric scores were added. The peer coaching method assisted the teacher-participants in presenting the lesson. The purpose of this stage is to ascertain how the ST practices of teachers affect the 21CS of the students. The pre-and post-survey questionnaire was used to determine students' 21CS. This is supported by qualitative data, which includes class observation, learning output analysis, and interviews.

All the gathered data were analyzed to determine the emerging PD model on the ST approach based on the recurring processes, relationships, and patterns in using of the ST approach in teaching and learning biology lessons. Data gathering in this study took place in "action experiments in authentic educational settings," which did not did not involve controlled conditions (Argyris, 1993, as cited in Elsawah et al., 2021). The researcher holds a dual role as the teacher and researcher, and in this regard, multimethod and triangulation are done to ensure the breadth and depth of the collected data (Elsawah et al., 2021).

Data Analysis

The paired sample t-test was used to determine the significant difference between the mean score rating of the teacher's response and students' perceived 21CS using SPSS version 25. The study satisfied the assumptions for the paired sample t-test. The transcripts from audio-video recordings, focus group discussions, interviews, and open-ended questionnaires were transcribed verbatim. It analyzed the patterns of ST aspects in teaching biology lessons, and their impact on developing students' 21CS and PD. Line-by-line coding was used to have detailed insights into data. The focused coding technique was used to identify and develop the concept that best fits the data. In-depth synthesis and analytic categorization of the initial codes were conducted to determine the adequacy of the collected data. The categories were further examined for integration in a larger context to specify the dimensions of the categories.

The ST pragmatic framework of Moore-Anderson (2021) was used to categorize the ST attributes of the content and activities given in Life Science. The three activities evaluated the teacher-participants' ST skills level using the Systems Model Rubrics. Each participant assessed the systems model that the other groups created after explaining the system's thinking dimensions. The group's oral and written explanations of their systems model outputs were analyzed to complement the quantitative data. This analysis aimed to further elucidate the ST skills and content knowledge demonstrated by the participants. They were asked to provide written responses on the designated worksheet and were allotted time for presentations to explain their models. This approach was implemented to mitigate the limitations of using a systems model solely to reveal the students' depth of understanding. The analysis of the systems model facilitates the assessment of the participants' level of ST skills in terms of system organization, system behavior, systems modeling, and cross-level reasoning.

Various methods were employed to ensure the credibility, reliability, and validity, including the integration of qualitative and quantitative data analysis, triangulation, thorough engagement in data collection, peer examination, and inter-rater agreement. Qualitative data were recorded and transcribed. The transcripts were read and rated according to the coding booklet and rubric. The coding and rating process was repeated multiple times to ensure that appropriate rubric levels were applied. Inter-rater reliability was established to confirm the reliability of the rubric.

There was prolonged engagement for internal validity as the researcher spent months with the teacher-participants. A naturalistic setting was created between the teachers and students while implementing their lessons using ST. This fostered rapport and trust with the participants. Triangulation was achieved by collecting multiple data sources, including survey questionnaires, reflection questions, focus group discussions, systems models, lesson exemplars, and video lessons. Peer review was conducted by examining the data and evaluating its interpretation. The volunteer participants were informed about the data collection process as part of the study.

Ethical Considerations

The College President and Graduate School Dean granted the permission to conduct the study. At the outset, participants were oriented about the course syllabus and content. They were informed that the information collected would be used in the study. The teacher-participants were informed of the study's purpose, advantages, and possible limitations. They were guaranteed data confidentiality and privacy. Upon signing the informed consent and agreement form, the participants acknowledged that their participation was entirely voluntary and that they could withdraw anytime without prejudice. Additionally, the orientation of the procedure for implementation of the lesson was provided to the teacher-participants. The researcher sought permission from the school division Superintendent to endorse the study's conduct in the teacher-participants' respective schools. A letter of request was then submitted to the School Head and Science Department Chair to allow the implementation of the lesson using ST developed by the teacher-participants. After securing approval to conduct the study, the teacher-participants provided informed consent to their students, explaining the purpose of the study and their role as student participants. The students' parents were given informed consent for their information and approval.

Results

This section presents the results of the systems thinking practices of the biology teachers regarding the four domains of PPST, and their implications on students' 21CS before and after the implementation of the ST biology lesson of the teachers. It also shows the PD model designed for biology teachers that would provide their ST skills. This is the result of an iterative process involving evaluation, observation, and reflection from its pilot testing and implementation over three terms, ultimately leading to the refinement of the STPDC.

RQ1. Systems thinking Practices of Biology Teachers in terms of:

a. ***Content Knowledge and Pedagogy***

The content knowledge and pedagogical practices of the teachers are shown in Table 3. The test revealed that there were significant differences in the result of Case Study 1 teacher-participants when it comes to systems organization before ($M=3.979$; $SD=0.711$) and after the course ($M=4.313$; $SD=0.441$); [$t(11)=2.766$, $p=0.018$]; and systems behavior before ($M=3.527$; $SD=0.890$) and after the course ($M=4.083$; $SD=0.495$); [$t(11)=3.458$, $p=0.005$]. However, the result also showed that there is no significant difference in the systems modeling practices of the teachers before ($M=3.222$; $SD=1.234$) and after the course ($M=3.750$; $SD=0.588$); [$t(11)=1.697$, $p=0.118$]. The result for the Case Study 2 teachers indicates significant differences in the three components of ST practices before and after the course. These results suggest that the teachers' participation in the STPDC enhances their understanding and teaching strategies concerning ST.

Table 3

Comparison of Systems Thinking Practices in Content Knowledge and Pedagogy Before and After STPDC

Component	Pre-Survey		Post-Survey		t-value	p
Case Study 1 (n=12)	M	SD	M	SD		
Systems Organization	3.979	0.711	4.313	0.441	2.766	0.018*
Systems Behavior	3.527	0.890	4.083	0.495	3.458	0.005*
Systems Modeling	3.222	1.234	3.750	0.588	1.697	0.118
Case Study 2 (n=18)						
Systems Organization	4.083	0.636	4.722	0.342	4.293	0.000*
Systems Behavior	3.833	0.660	4.630	0.394	5.672	0.000*
Systems Modeling	3.444	0.616	4.463	0.487	6.633	0.000*

(*e.g., Note.* M= Mean scores are based on a 5-point Likert scale, with higher scores indicating greater proficiency in systems thinking practices. SD = Standard Deviation. *t* = computed *t-value.* *p <0.05)

b. Learning Environment

As presented in Table 4, there were significant differences in the promotion of ST and purposive learning before (M=3.950; SD=0.678) and after (M=4.300; SD=0.575; [t(11)=2.836, p=0.016]); and the management of classroom structure and activities before (M=3.783; SD=0.904) and after (M=4.217; SD=0.706; [t(11)=3.767; p=0.003]) the STPDC of the Case Study 1 participants. It was also observed that Case Study 2 participants had significant differences in the promotion of ST and learning before (M=4.311; SD=0.474) and after (M=4.756; SD=0.340; [t(17)=-3.205, p=0.005]); and management of classroom structure and activities before (M=4.122; SD= 0.395) and after (M=4.711; SD=0.345; [t(17)=-4.804; p=0.000]) the STPDC.

Table 4

Comparison of Systems Thinking Practices in Terms of Learning Environment Before and After STPDC

Components	Pre-Survey		Post-Survey		t-value	p
Case Study 1 (n=12)	M	SD	M	SD		
Promotion of systems thinking and purposive learning	3.950	0.678	4.300	0.575	2.836	0.016*
Management of classroom structure and activities	3.783	0.904	4.217	0.706	3.767	0.003*
Case Study 2 (n=18)						
Promotion of systems thinking and purposive learning	4.311	0.474	4.756	0.340	3.205	0.005*
Management of classroom structure and activities	4.122	0.395	4.711	0.345	4.804	0.000*

(*e.g.*, *Note.* M= Mean scores are based on a 5-point Likert scale, with higher scores indicating greater proficiency in systems thinking practices. SD = Standard Deviation. *t* = computed *t-value.* *p <0.05)

These findings suggest that after participating in the STPCD, the participants gained strategies to effectively implement and integrate ST in their classes to help the students understand real-life biological phenomena. The teachers provided strategies that allow students to solve real-life issues, use systems models and simulations, and make scientific judgments to develop students' social and cross-cultural skills.

c. Curriculum and Planning

This is based on the ability of the teachers to design lesson exemplars using ST characteristics and tools aligned with the MELCs for Life Science. As shown in Table 5, there were significant differences in the planning and management of teaching and learning process before (M=3.583; SD = 0.990) and after (M=4.021; SD=0.644; [t(11); p=0.040]); and professional collaboration to enrich teaching practices before (M=3.750; SD=0.623) and after (M=4.167; SD=0.718; [t(11)=2.803; p=0.017]) the STPDC of the Case Study 1 participants. However, there was no significant difference in the relevance and responsiveness to learning programs before (M=3.750; SD=0.754) and after (M=4.083; SD=0.669; [t(11)=1.773]) the STPDC. On the other hand, Case Study 2 participants showed significant differences in all the components before and after the STPDC. These components include planning and management of the teaching and learning process [t(17); p=0.001]; relevance and responsiveness to the learning program [t(17)=3.112; p=0.006]; and professional collaboration to enrich teaching practice [t(17)=3.112; p=0.006].

The results indicate that participants acquired greater knowledge and skills in designing their lesson plans to effectively integrate ST strategies into their respective lessons. This includes proper alignment of lesson objectives with MELCs and congruent activities and assessments related to those objectives.

Table 5

Comparison of Systems Thinking Practices in terms of Curriculum and Planning Before and After STPDC

Component	Pre-Survey		Post-Survey		t(11)	p
Case Study 1 (n=12)	**M**	**SD**	**M**	**SD**		
Planning and management of the teaching and learning process	3.583	0.990	4.021	0.644	2.333	0.040*
Relevance and responsiveness to learning programs	3.750	0.754	4.083	0.669	1.773	0.104
Professional collaboration to enrich teaching practices	3.750	0.623	4.167	0.718	2.803	0.017*
Case Study 2 (n=18)						
Planning and management of the teaching and learning process	3.618	0.844	4.597	0.375	4.252	0.001*
Relevance and responsiveness to learning programs	3.833	0.924	4.611	0.502	3.112	0.006*
Professional collaboration to enrich teaching practices	3.833	0.924	4.611	0.502	3.112	0.006*

(*e.g., Note*. M= Mean scores are based on a 5-point Likert scale, with higher scores indicating greater proficiency in systems thinking practices. SD = Standard Deviation. *t* = computed *t-value.* *p <0.05)

d. Assessment and Reporting

This is shown by teachers based on how they design their activities and assessments, as reflected in their lesson exemplars and responses to open-ended questions and focus group discussions. As shown in Table 6, there were no significant differences in the components for assessment and reporting except for the use of assessment data to enhance teaching and learning progress before (M=3.771; SD=1.063) and after (M=4.500; SD=0.670; [t(11)=2.020); p=0.014) the STPDC of the Case Study 1 participants. For Case Study 2 participants, the test revealed that there were significant differences in all of the components except for monitoring and evaluating the learning programs before (M=4.389; SD=0.778) and after (M=4.778; SD=0.428; [t(17)=1.941; p=0.069).

Table 6

Comparison of Systems Thinking Practices in Terms of Assessment and Reporting Before and After STPDC

Component	Pre-Survey		Post-Survey		t-value	p
Case Study 1 (n=12)	**M**	**SD**	**M**	**SD**		
Design, select, organize, and utilize assessment strategies	3.972	0.731	4.389	0.633	1.820	0.096
Monitor and evaluate the learning programs	4.500	0.522	4.583	0.669	0.432	0.674
Giving Feedback and communicating students' learning progress to improve learning	4.208	0.656	4.417	0.634	1.164	0.269
Use of assessment data to enhance teaching and learning progress	3.771	1.063	4.500	0.670	2.020	0.014*
Case Study 2 (n=18)						
Design, select, organize, and utilize assessment strategies	4.204	0.658	4.630	0.377	2.310	0.034*
Monitor and evaluate the learning programs	4.389	0.778	4.778	0.428	1.941	0.069
Giving Feedback and communicating students' learning progress to improve learning	4.167	0.664	4.778	0.392	3.510	0.003*
Use of assessment data to enhance teaching and learning progress	3.889	0.544	4.708	0.356	4.853	0.000*

(*e.g.*, *Note*. M= Mean scores are based on a 5-point Likert scale, with higher scores indicating greater proficiency in systems thinking practices. SD = Standard Deviation. *t* = computed *t-value.* *p <0.05)

During the course, teachers' assessments mainly focused on recalling facts and basic concepts, limiting the evaluation of students' critical thinking and problem-solving skills. To effectively measure these skills, rubrics should be developed to assess students' systems model outputs.

RQ2. Implication of Biology Teachers' Systems Thinking Practices to Students' 21st Century Skills Development in terms of:

The ability of the teachers to explicitly integrate ST to foster an in-depth understanding of biological systems and provide innovative solutions to real-life issues and concerns would help develop students' 21CS. The students would be able to recognize and understand the complex systems involved in current issues and problems. In this regard, the development of students' 21CS was determined before and after the implementation of the ST biology lesson.

a. Information, Media, and Technology

Information, media, and technology literacy enable students to use information and technology efficiently and effectively. Based on Table 7, there was a statistically significant difference between the pre-survey (M=3.982; SD=0.550) and post-survey scores (M=4.224; SD=0.640; [t(109)=4.384; p=0.000]) of students in terms of their perceived information literacy.

This indicates that the ST activity allows students to organize and synthesize the information gathered to address real-life phenomena they should investigate. The students accurately selected information to solve problems. The interview revealed that some teachers provided links and articles for students to read regarding the real-life issues they would address in the systems model activity. They also allocated time for students to conduct research, which would enhance their understanding of the topic.

Table 7

Perceived Information Literacy of Students Before and After Implementing Lessons Using Systems Thinking (N=110)

Information Literacy	M	SD	t(109)	p
Pre-survey	3.982	0.550	4.384	0.000*
Post-Survey	4.224	0.640		

(*e.g., Note.* M= Mean scores are based on a 5-point Likert scale, with higher scores indicating greater proficiency in 21CS. SD = Standard Deviation. *t* = computed *t-value.* *p <0.05) *a.2. Technological literacy.*

Table 8 shows that there was a statistically significant difference between the pre-survey (M=4.017; SD=0.640) and post-survey scores (M=4.176; SD=0.706; [t(109)=2.546; p=0.012]) of students in terms of their perceived technological literacy. The students use ICT to gather data that they could use to understand the phenomena and make the model of their system.

Table 8

Perceived Technological Literacy of Students Before and After Implementing Lessons Using Systems Thinking (N=110)

Technological Literacy	M	SD	t(109)	p
Pre-survey	4.017	0.640	2.546	0.012*
Post-Survey	4.176	0.706		

(*e.g., Note.* M= Mean scores are based on a 5-point Likert scale, with higher scores indicating greater proficiency in 21CS. SD = Standard Deviation. *t* = computed *t-value.* *p <0.05)

Most students constructed models of their systems using manila paper, markers, and colored paper. They could not utilize other technological tools for creating and presenting their work due to limited access to computers and internet connections. However, it was noted that some groups from Grade 9 and Grade 10 managed to present their activity outputs using PowerPoint presentations and Canva. Additionally, they could not share their activity outputs on social platforms; their work was only presented in class before their teacher and classmates.

b. Learning and Innovation

Systems thinking is a teaching and learning strategy that teachers could use to build students' 21CS and in-depth understanding of science concepts. It uses scenario-based or problem-based learning, contextualized learning, and inquiry-based learning.

b.1 Critical thinking and problem-solving skills.

As shown in Table 9, the students' critical thinking and problem-solving skills differed significantly before (M=3.547; SD=0.749) and after (M=4.002; SD=0.721; [t(109)=6.447; p=0.000]) the implementation of the ST lesson.

Table 9

Perceived Critical Thinking and Problem-Solving Skills of Students Before and After Implementing Lesson Using Systems Thinking (N=110)

Critical Thinking and Problem-Solving skills	M	SD	T(109)	p
Pre-survey	3.547	0.749	6.447	0.000*
Post-Survey	4.002	0.721		

(*e.g., Note.* M= Mean scores are based on a 5-point Likert scale, with higher scores indicating greater proficiency in 21CS. SD = Standard Deviation. *t* = computed *t-value.* *p <0.05)

The students investigated real-life problems based on what they observed in their community. The students processed the development of the systems model through scaffolding questions provided during discussion and activities. The presented systems model of the students was predominantly linear. However, some interconnections were made among the components to answer the big question. The students also tried to identify the causes, effects, and solutions by providing color codes as instructed by the teacher.

b.2 Creativity and innovation

As shown in Table 10, the students' creativity and innovation skills differed significantly before (M=3.685; SD=0.718) and after (M=4.122; SD=0.738; [t(109)=6.049; p=0.000]) the implementation of the ST lesson.

Table 10

Perceived Creativity and Innovation of Students Before and After Implementing Lesson Using Systems Thinking (N=110)

Creativity and Innovation	M	SD	t(109)	p
Pre-survey	3.685	0.718	6.049	0.000*
Post-Survey	4.122	0.738		

(*e.g., Note.* M= Mean scores are based on a 5-point Likert scale, with higher scores indicating greater proficiency in 21CS. SD = Standard Deviation. *t* = computed *t-value.* *p <0.05)

Students must be creative thinkers and innovative in providing science-based solutions to the problems and issues given to them. The students provided common practices and solutions to the big problem in their ST activity,. Some teachers included technological advancement as a way for students to provide alternative solutions for the given problem. However, it was also revealed in the interview that some teachers associated creativity with the ability of the students to design their work aesthetically using borders, art materials, and colored papers.

c. Communication

This involves the ability of the students to articulate their thoughts using oral, written, and nonverbal forms, to demonstrate the ability to work effectively and respectfully with a diverse team, and assume shared responsibility.

c.1 Communication skills.

Based on Table 11, there is a significant difference in the communication skills of the students before (M=3.882; SD=0.706) and after (M=4.155; SD=0.721; [t(109)=4.243; p=0.000]) implementing the lesson

Table 11

Perceived Communication Skills of Students Before and After Implementing Lesson Using Systems Thinking (N=110)

Communication Skills	M	SD	t(109)	p
Pre-survey	3.882	0.706	4.243	0.000*
Post-Survey	4.155	0.721		

(*e.g., Note.* M= Mean scores are based on a 5-point Likert scale, with higher scores indicating greater proficiency in 21CS. SD = Standard Deviation. *t* = computed *t-value.* *p <0.05)

It was observed that the students could communicate their systems model with relevant information. They provided facts and data with references for the evidence that supports their statement. The students responded they believed that they were clearly explained detailed and relevant information (78%), and only a few mentioned that they could not explain well (22%). However, most students relied on cue cards or notes on mobile phones to read their explanations about the model of their systems.

c.2 Collaboration.

Table 12 shows no significant difference [t(109)=1.392; p=0.167] in how students work together and share responsibility with their group mates. This may be attributed to the various group activities conducted by the teachers to promote interaction among students. The teachers observed how their students worked collaboratively.

Table 12

Perceived Collaboration of Students Before and After Implementing Lesson Using Systems Thinking (N=110)

Collaboration	M	SD	t(109)	p
Pre-survey	4.293	0.682	1.392	0.167
Post-Survey	4.383	0.715		

(*e.g., Note.* M= Mean scores are based on a 5-point Likert scale, with higher scores indicating greater proficiency in 21CS. SD = Standard Deviation. *t* = computed *t-value.* *p <0.05)

The students could share their ideas and reach a common decision when creating their models. The students mentioned in the survey questionnaire that they participated in their group by giving suggestions to answer the big problem (38%). Peer evaluation in group activities helps students understand expectations and fosters shared responsibility.

d. Life and Career Skills

Life and career skills involve flexibility and adaptability, initiative and self-direction, productivity and accountability, and leadership and responsibility (DepEd, 2019). They are part of living in a diverse and complex world. Table 13 shows no significant difference [t(109)=0.858; p=0.393] in the perceived life and career skills of the students.

Though the results did not show any significant difference, the interviews revealed that students gained a sense of leadership and responsibility. The students were assigned roles to achieve the group's goal. They shared ideas and helped make the model leading to productivity and accountability. They respected diverse opinions and valued a positive learning environment to achieve goals.

Table 13

Perceived Life and Career Skills of Students Before and After Implementing Lesson Using Systems Thinking (N=110)

Life and Career Skills	M	SD	t(109)	p
Pre-survey	4.240	0.610	0.858	0.393
Post-Survey	4.296	0.666		

(*e.g., Note.* M= Mean scores are based on a 5-point Likert scale, with higher scores indicating greater proficiency in 21CS. SD = Standard Deviation. *t* = computed *t-value.* *p <0.05)

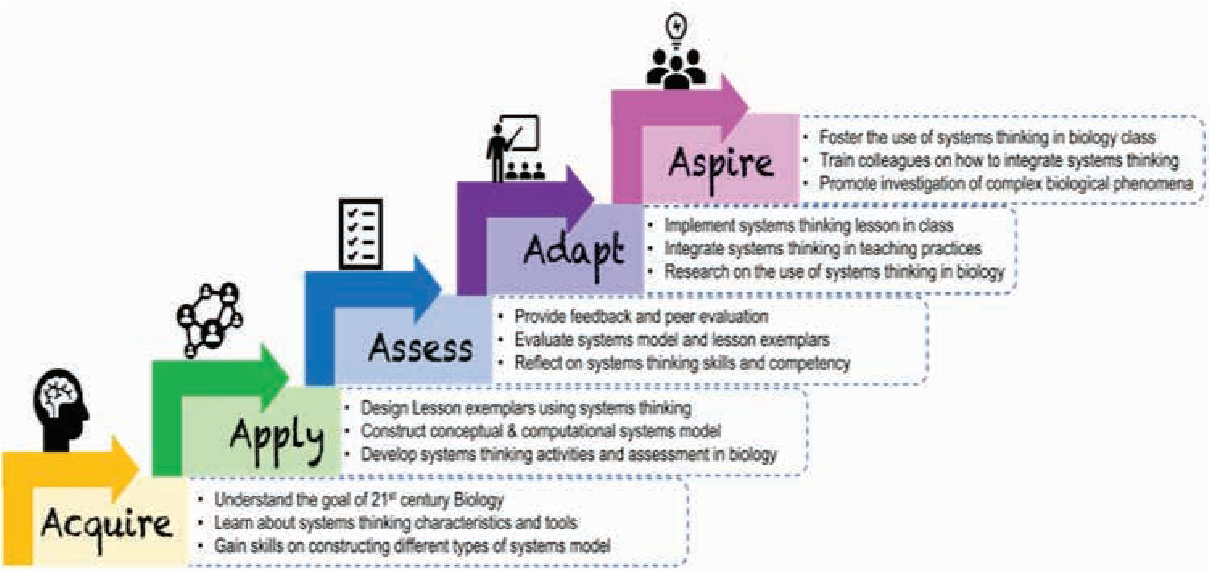
RQ 3. Professional Development Model on Systems Thinking for Biology Teachers

The PD model designed for biology teachers provides a comprehensive framework for developing their knowledge and skills in ST through five key stages: Acquire, Apply, Assess, Adapt, and Aspire. This structured approach results from an iterative process involving evaluation, observation, and reflection from its pilot testing and implementation over three terms, ultimately leading to the refinement of the STPDC. The 5As PD model in ST is shown in Figure 2.

Acquire: Teachers begin by gaining an understanding of the goal of Biology for the 21st Century. This stage emphasizes learning the characteristics and tools of ST. Participants construct systems models and make cross-level connections as they explore various biological phenomena.

Figure 2

Systems Thinking Professional Development Model for Biology Teacher



Apply: Teacher-participants develop various systems models to visualize and explain a biological phenomenon. They create conceptual systems models using causal loops and stock-and-flow diagrams, and they may use technological applications such as SageModeler and Vensim to present computational systems models. The design of lesson exemplars in biology, including activities and assessments that utilize ST characteristics and tools, is also a focus in this stage.

Assess: This stage involves self-evaluation and reflection on the teachers' ST skills and competencies. Participants assess their proficiency in creating systems models to explain specific biological issues, allowing them to track their progress throughout the course in self-regulation and metacognition development. Peer evaluation enhances their ability to provide constructive feedback based on content and effort, fostering a culture of peer coaching and mentoring that positively impacts lesson outcomes and increases confidence in implementing lessons.

Adapt: Teachers are encouraged to implement their developed lesson exemplars in actual classroom settings. This includes adhering to their school's standards for lesson planning and instructional materials development. Successful integration of ST is supported by school leadership, helping teachers reflect on their lessons' strengths and weaknesses through direct observation and student interviews. The data collected serve as a baseline for assessing student performance in life sciences and pinpointing areas for enhancing students' 21st Century Skills.

Aspire: In the final stage, teachers are prepared to independently promote the integration of ST in their biology lessons. Equipped with the requisite knowledge and skills, they can engage in classroom observations, facilitate Learning Action Cell (LAC) sessions, and conduct action research. They may also share their insights with colleagues, leading training sessions on integrating ST in teaching practices, which contributes to their growth as resource speakers in ST and supports the development of their RPMS-PPST portfolios for career advancement. Furthermore, this stage emphasizes fostering scientific, technological, and environmental literacy among students, preparing them for the demands of the 21st century.

The 5As PD model is a systematic approach to enhancing the competencies of biology teachers in ST. Each stage is designed to ensure that teachers not only learn theoretical aspects of ST but also apply, assess, adapt, and aspire to implement ST effectively in their educational practices. Ultimately, this model aims to contribute to improving biology education while equipping teachers to foster 21CS in their students.

Discussion

Systems thinking can be utilized to create scenario-based or problem-based activities that evaluate students' collaborative problem-solving abilities (Grohs et al., 2018). Although ST has not been fully incorporated into classroom practices, Gilissen et al. (2020) established guidelines for implementing ST in secondary biology education. This includes introducing systems characteristics, applying ST in various contexts, focusing on enhancing students' understanding of phenomena through one or two systems characteristics, and explicitly using ST language during lessons. In the study of Akiri et al. (2020), a gradual, long-term process for introducing and developing ST skills is essential for helping teachers practice systems modeling. Giving more time for teachers to engage in ST practice may enhance their systems modeling skills.

Teachers should create lesson plans that increase students' understanding of biological systems, explore real-life situations, and use cross-level reasoning and visualization techniques. ST helps students identify elements within systems and connect them with biological processes. This underscores the importance of teachers unlocking students' prior knowledge and addressing difficulties in learning biology concepts and processes. According to Windschitl (2019), teachers should transform biology education for 21st-century learners. Helping students understand the main concepts of the lecture, encouraging sense-making conversation, offering a range of evaluation techniques, and giving examples of how biologists work can assist in achieving this. Gradually integrating ST in the classroom could enhance students' abilities in constructing conceptual models and computational models.

It is also vital for teachers to provide relevant guiding questions in addition to structured instructions. Gilissen et al. (2021) noted that explicit scaffolding questions would aid students' cross-level reasoning regarding biological organizations. Incorporating "active reading strategies" in science classes would foster responsibility among students in gathering information, potentially leading to enhanced academic achievement and the development of 21CS (Gillis & MacDougall, 2007). The deliberate use of ST characteristics in lessons may offer a framework for teachers and students to explore phenomena in an integratively and coherent way.

Regarding the implication of teachers' systems thinking practices on students' 21CS, teachers should use systems model output to monitor students' understanding of biology. They should receive training on 21CS development and its assessment beyond quarterly exams to determine learning progress. Developing appropriate rubrics for assessing students' systems model outputs is essential to provide relevant measurements of their knowledge and skills as demonstrated in their outputs. Gupta and Chauhan (2020) discovered that detailed rubrics help students concentrate on the skills they need to develop, clarifying the expected output or performance, which fosters constructive learning. Several studies utilize rubrics to assess students' ST skills. Rempfler and Uphues (2012) created a competence model for geographical systems competence, encompassing three competence dimensions: system organization, system behavior, and system-adequate intention to act. This competence model can be employed to diagnose students' proficiency in geographic systems.

This indicates that students were more cognizant of the information needed to construct their system model. They can evaluate whether the sources of information are credible and fact-based. Porter (2005) noted that information literacy skills are crucial for biology students to grasp the topics effectively and to conduct research. He highlighted that instruction in information literacy led to well-researched and well-written assignments and papers. This is corroborated by the study of Saptasari et al. (2019), which integrated information literacy skill rubrics into project-based activities for biology students. They discovered that information literacy significantly influences students' learning outcomes in biology. This suggests that teachers should provide strategies to help students enhance their information literacy skills. This may include offering links to journal articles and science-based data for student access. Students should also practice locating quality references and should be guided on writing their academic work ethically.

In addition to this, teachers should utilize digital devices and design digital literacy rubrics to effectively develop students into technologically literate individuals. Teachers with a high level of digital literacy could maximize students' learning in biology (Hasanah et al., 2023). This implies that teachers should provide explicit strategies to help develop students' technological literacy. Teachers should also explore technological tools that enable students to create system models, such as SageModeler and Vensim. This should include orientation to guide students and maximize their use of technology in learning. Students should also be encouraged to create original and innovative content that demonstrates the application of biological concepts and processes in real-life situations.

In this perspective, the problem-solving model in biology may enhance students' critical thinking skills (Utami & Nurcahyo, 2023). Snyder and Snyder (2008) noted that critical thinking and problem-solving skills can be improved through active learning processes in problem-based or collaborative activities. Through these activities, students can offer evidence-based explanations. They can also demonstrate how they accurately identify the conclusions and implications of the problems being investigated. Allowing students to construct their models using systems thinking would facilitate cross-level reasoning and innovative solutions to real-world problems. It is crucial for teachers to guide students in creating their systems models. Providing step-by-step instructions on creating the model is necessary for students to exhibit the characteristics of systems thinking.

Moreover, the study by Ruth et al. (2021) revealed that teachers' creative skills in the classroom positively influenced students' academic performance. It was suggested that teachers could enhance creativity in the classroom by encouraging freedom of expression, engaging with student ideas, cultivating a compassionate learning environment, and rephrasing assignments to promote creative thinking. Teachers should receive training on how to develop creative skills in their teaching. One example was assessing students' creativity in learning biology through posters and practicum reports. Juanengsih et al. (2017) measured creativity using four indicators: originality, flexibility, fluency, and elaboration. The results indicated that students' creativity levels were higher in creating posters than in writing practicum reports. The students could express their ideas more effectively through visualization than writing tasks.

This is in support of the study of Purnomo and Fauziah (2018) that advocate for scientific communication skills through the use of pictorial analogies. It was found that presenting pictorial analogies could aid in developing students' communication skills by selecting appropriate materials for illustrations and analyzing what needs to be communicated. Students who participated in the oral skills development intervention exhibited improved academic performance and a positive attitude. The intervention encompasses verbal and non-verbal communication, audience engagement, effective presentation techniques, the use of visual and audio materials, impromptu speaking strategies, and anxiety management. Teachers should enable students to communicate their ideas and outputs, allowing them to solve issues from different perspectives and provide alternative solutions. The students should be able to effectively demonstrate their cognitive abilities in understanding real-life phenomena (Anderman & Sinatra, n.d.). They should identify their target audience, introduce biological theories and scientific studies, utilize various media for communication, and provide feedback and assessment of their communication skills (Shivni et al., 2021).

Furthermore, teachers should provide explicit strategies for active participation, orient students on shared responsibility, and observation checklist for collaboration. Collaborative learning cultivates a positive learning environment. It enhances metacognition and communication (Saavedra & Opfer, 2012), and empowers independent work (Stehle & Peters-Burton, 2019). Teachers play a crucial role in imparting life skills to students. Fidan and Aydogdu (2018) found that students and science teachers defined life skills as the ability to "maintain quality of life, cope with difficulties, and transform learning into action." However, teachers focus on the content teaching hinders students' life skills development. STPDC enhances instructional practices and improves student outcomes by promoting science education and career readiness, enhancing critical thinking, problem-solving, information literacy, and communication.

This research developed and refined the STPDC for biology teachers, establishing the 5As PD model. This model focuses on understanding ST, using ST tools, and designing effective lessons. Teachers are encouraged to apply ST skills in their classrooms, allowing direct observation and assessment. Further, this research builds on the findings of Pineda et al. (2022), highlighting that the design and framework of professional development programs are crucial for fostering teacher engagement and skill enhancement. Research by Morales et al. (2021) shows that STEAM teachers demonstrate high levels of participation in PD programs, especially when involved in activities like lesson exemplar development that empower them to craft engaging, mastery-oriented lessons within STEAM disciplines. The PD program not only promotes active participation but also encourages reflective practice through constructive feedback mechanisms. Additionally, Ancho and Arrieta (2021) emphasize the importance of involving teachers in the PD process and allowing them to express the challenges they encounter in their instructional practices. This creates a more responsive and supportive professional development environment. The findings confirm that a well-structured PD program can significantly enhance teaching practices while simultaneously improving student outcomes through the strategic implementation of ST principles.

There are few studies related to professional development on ST. This includes the research by Streiling et al. (2021), who investigated the pedagogical content knowledge of biology teachers following their participation in a training program. The results indicated that after the training, there was an enhancement in the ST performance of their students. It was also suggested that the duration of the training be extended to better support the development of teachers' ST skills. This is corroborated by Ritchie (2017), whose findings revealed that increased attempts to implement lessons using

ST positively influence teachers' self-efficacy. In this context, Semiz and Teksöz (2019) recommended offering an ST course aimed to develop teachers' pedagogical content knowledge for effectively implementing ST with their students.

Integrating ST characteristics and tools in biology lessons can enhance students' 21CS by promoting scientific journals, accurate data, and technological applications. This approach enhances information and technological literacy, cross-level reasoning, hierarchical systems model, and life and career skills, including leadership, accountability, and teamwork. In this context, ST in Biology should focus on applying biological concepts and processes to understand and solve real-life problems. Teachers should not only learn about ST but also how to construct systems model activity. They should demonstrate how to create a hierarchical systems model by providing explicit samples. Furthermore, developing 21CS is essential for students to show their ability to construct systems models that present innovative solutions.

Conclusion

This study concludes that the Professional Development on Systems Thinking significantly enhanced the pedagogical practices of biology teachers across several key dimensions: content knowledge, pedagogy, learning environment, curriculum planning, and assessment. By integrating systems thinking into their teaching methodologies, the teachers were able to foster a deeper understanding of biological concepts among their students through the exploration of real-life phenomena. This approach not only enriched the learning experience but also contributed to the enhancement of students' 21st century skills. The students demonstrated their ability to utilize scientific information and technological tools to construct models, communicate effectively, and engage in shared responsibilities during classroom activities.

The findings of this study indicate that ST serves as a powerful teaching and learning strategy, empowering learners to understand the structure, organization, and behavior of systems reflected in real-life scenarios. Implementing model-based teaching practices further reinforced the principles of ST and enhanced students' cross-level reasoning concerning biological phenomena (Gilissen et al.,2021; Momsen et al.,2022). The systems modeling approach offers a clear method for visualizing phenomena, aiding comprehension.

Central to this research was the development, evaluation, and refinement of the STPDC for biology teachers, during which the 5As PD model emerged—Acquire, Apply, Assess, Adapt, and Aspire. The model guides biology teachers through ST competencies, model creation, and lesson design, encouraging them to apply ST skills in the classroom, assess student engagement, and self-evaluate ST implementation. STPDC model enhances teacher competencies and teaching practices in life sciences, addressing the gap in professional training. Teachers may effectively utilize the gained competencies for career advancement, classroom observations, LAC sessions, and action research projects.

This study provides valuable insights into the experiences and practices of public high school biology teachers engaged in a Graduate School program, mainly focusing on implementing ST in the classroom. While it has limitations by focusing solely on a specific context, it highlights the significance of ST in enhancing students' 21CS. To address the identified limitations and further enhance the integration of ST in biology education, several recommendations are made:

1. ***Training Programs:*** Implement the STPDC as a structured training program for pre-service and in-service teachers, to enhance their ST skills.

2. ***Scenario-Based Activities and Assessments:*** Integrate an ST approach when developing scenario-based activities and authentic assessments in biology to promote a more profound learning experiences. Explicitly assess 21CS in classroom practices, utilizing standardized tests and rubrics to measure and track students' development in these areas.

3. ***Workshops and Mentoring:*** Organize workshops, mentoring, and peer coaching for biology teachers to create effective ST lessons and strategies. Encourage biology teachers to engage in discourse with scientists and experts to gain interdisciplinary perspectives on real-life issues connected to biological concepts.

4. ***Action Research:*** Promote action research initiatives among teachers to explore the implications of ST on students' conceptual understanding and cross-level reasoning across different grade levels and disciplines in science.

By implementing these recommendations, educational stakeholders can enhance the teaching practices of biology teachers, thereby fostering students' engagement and improving their competencies in ST and 21CS.

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