Effect of science process skills-based teaching approach on secondary school students' scientific epistemological beliefs

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Abstract

This study sought to examine the effect of the Science Process Skills-Based Teaching Approach (SPSBTA) on students' scientific epistemological beliefs (SEBs). The study used a mixed-method research approach with a quasi-experimental design. Two schools with relatively organized laboratories were selected and randomly assigned to experimental and comparison groups, resulting in a sample of 78 students. Data were collected through a questionnaire, interview, and observation and quantitatively analyzed using mean, standard deviation, independent sample t-test, ANCOVA, and qualitatively with narration. The findings showed that the students in the experimental group who participated in the SPSBTA intervention demonstrated higher epistemological improvement than those in the comparison group. However, there was no statistically significant difference between genders. The study concludes that SPSBTA was more effective than the conventional method in improving SEBs. Based on the findings of this study, it is recommended that concerned bodies should encourage biology teachers to apply SPSBTA.

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Introduction

Teaching students to understand scientific concepts, developing thinking abilities to transfer knowledge, and developing science process skills are the aims of learning science in the 21st century (Aidoo et al., 2016). Researchers in science education claim that students should know how to obtain knowledge and recognize how that knowledge is created in science disciplines (Schiefer et al., 2022). These personal beliefs about the nature and acquisition of scientific knowledge, including the meanings of scientific knowledge, how scientific knowledge is created, and how this knowledge is evaluated are epistemological views (Hofer & Pintrich, 1997). In science learning, epistemological beliefs and inquiry of

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science process skills, like asking questions, making predictions, planning procedures, and interpreting results, are two holistic concepts that complement each other (Mete, 2023). In addition, epistemological beliefs (hereafter EBs) have a role both as a prerequisite for learning and a learning goal of science learning (Kampa et al., 2016). Due to this, epistemological views are the focus of science education (Kaçar, 2023). Consequently, researchers repeatedly investigated the linkage of EBs with different teaching-learning-related variables. For example, some studies on EBs have shown that students with sophisticated beliefs are positively correlated with students' preferences for approaches to learning, academic achievement, learning motivation, and an understanding of science, scientific literacy performance, and problem-solving (Elby et al., 2016; Greene et al., 2018; Guo et al., 2022; Kahsay, 2019; Lin & Tsai, 2017).

In the current situation, increasing attention has been paid to investigating the impacts of different types of inquiry-based teaching approaches on students' scientific epistemological beliefs (hereafter SEBs). However, there is an imperative but often underrated argument on inquiry-based approaches that should be implemented in schools to develop scientific epistemological beliefs. For example, Çoban (2013) showed that argument maps-supported inquiry-based teaching did not affect epistemological views. On the other hand, some researchers (Belay et al., 2023; Schiefer et al., 2020) demonstrated improvements in SEBs after the intervention of various inquiry-based practical activities. For instance, Schiefer et al. (2020) found that primary school students' beliefs about the certainty, development, and justification of knowledge improved with an inquiry-based learning strategy.

In learning biology, learners should practice discovering answers to problems; in doing so, students are required to have different science process skills (hereafter SPS) to perform an activity(Pengestuti et al., 2023). Due to this reason, scholars have suggested that biology learning at schools must involve processes that enable learners to practice and improve their SPS (Purnomo et al., 2021). Conversely, some scholars, for example, Cramman et al. (2021), have shown that in most developing countries' schools and universities, the old-fashioned practical work approach is still in practice due to the teacher-centered teaching approach in the classroom. This approach emphasizes acquiring knowledge from influential sources like teachers but does not prioritize facilitating students to construct new concepts for knowledge's sake; hence, students do not improve their SEBs through their participation in school science (Belay et al., 2023). Moreover, as Assefa (2020) pointed out, in most of the activities included in Ethiopian science textbooks, most experiments do not allow students to engage in scientific processes like observation and describe their observations in scientific knowledge construction.

Furthermore, based on our review results and the arguments of some scholars (Beumer, 2019; Teshager et al., 2021), there are few and contradictory empirical studies that address the effect of inquiry-based biology learning on SEBs at the global level. For example, Beumer (2019) found that teaching biology courses with inquiry methods did not affect students' epistemological beliefs. Conversely, Westerlund and Chapman (2017) and Hoskins and Gottesman (2018) revealed that student-centered biology learning methods enabled students to shift from non-expert-like thinking to more expert-like EBs in students. This contradictory finding might be due to various reasons, including the discipline and domain-specific nature of EBs, the nature of active learning methods(Urhahne & Kremer, 2023), the period of interventions (Kazeni & Onwu, 2013), and differences in grade levels (Ongowo, 2022).

Besides, the analysis of the existing literature to show how inquiry-based approaches affect students' SEBs based on gender showed inconsistent reports on the effect of inquiry-based approaches on learners' SEBs differences based on gender. Some scholars, such as Conley et al. (2004) and Kaynar (2007), have shown that inquiry approaches had no significant effect on the differences between male and female students' SEBs. For example, Conley et al. (2004)demonstrated that although there was a change in SEBs, there was no significant difference in EBs between male and female students after the intervention. On the contrary, Chai et al. (2006) and Belet and Guven (2011) analyzed the EBs and concluded that female student teachers had more developed EBs. Besides, in the Ethiopian current situation, some numerical changes are seen in the schools with a higher female ratio than males. Hence, it is necessary to investigate how much the gap in the learning variables is closing in academic settings due to the increase in female participation in schools. Therefore, the present researchers are also initiated to investigate the effect of science process skills integrated inquiry based teaching approach, on Ethiopian students' SEBs based on gender as one objective.

Many studies e.g.,(Atasoy & Küçük, 2020; Belay et al., 2023; Schiefer et al., 2020) investigated the effect of inquiry-based biology teaching on students' EBs. Each one was employing a quantitative approach with a quasi-experimental design. With this method, it is challenging to determine deeper underlying meanings and explanations because of their effect and their meanings in a particular context (Rahman, 2020).In addition, recent study by Ongowo (2022) also indicated the need for employing a mixed-method perspective on students' EBs to complement the weakness of one method with another. Accordingly, this study used a mixed method quasi-experimental design to obtain methodologically demanding information about process-skills-integrated inquiry-based learning. Moreover, to our knowledge, no study investigated the impacts of science process skills-based teaching approach on SEBs.

In Ethiopian schools, most science teachers use an old-fashioned teacher-centered approach to teach basic sciences such as chemistry, physics, and biology for various reasons (Gbre-eyesus, 2017). For instance, as some studies have shown, most government schools have rarely equipped laboratories (Ayicheh, 2020), lack well-trained lab technicians (Negesse & Shitaw, 2021), and have a large number of students in a class (Tiruneh et al., 2019), among other related challenges. Due to these problems, students in most secondary schools in Ethiopia are learning science courses through a teacher-centered approach without engaging in basic practical activities that enable them to practice SPS (Nigussie et al., 2018). This finding indicates that practical activities are also presented using a traditional practical work approach. Therefore, student-centered, process-oriented strategies like a science process skills-based teaching approach (hereafter SPSBTA) might be the solution to facilitate the knowledge construction process through the student's active participation in scientific inquiries.

Biology studies life and living organisms, and cells are the heart of life; the cell is a fundamental concept in biology. Although cell biology knowledge is relevant and significant, learning about cells and mastering the concept is difficult for biology students (Isma'il &

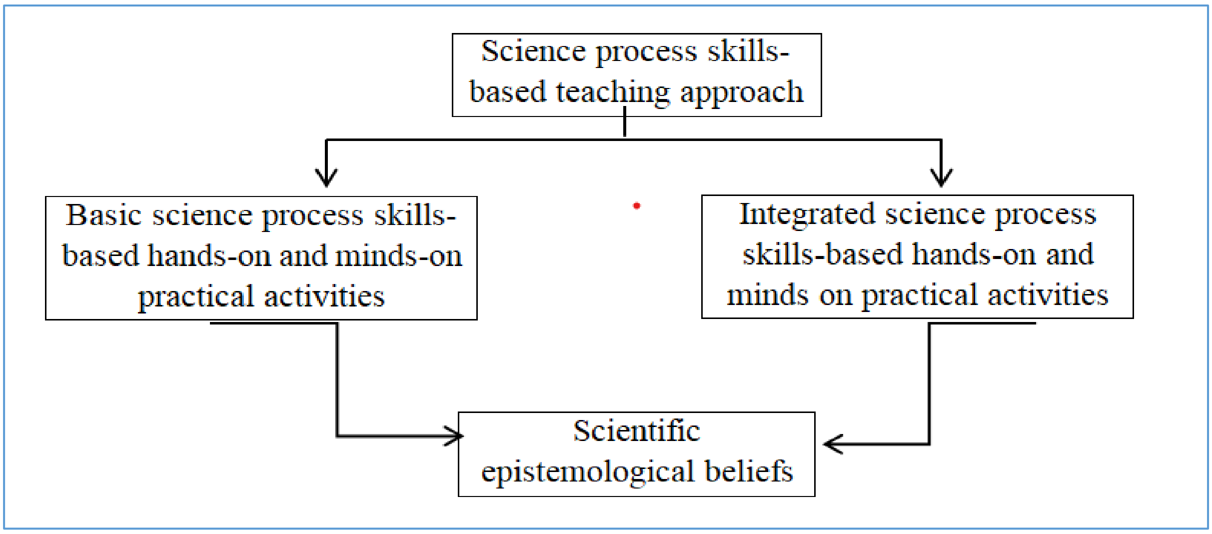
Matazu, 2024). For example, the study by Salleh et al. (2021) investigated high school students' problems with biology concepts and reported ideas associated with the cell as challenging for students to master. Hence, scholars, e.g., (Cherono et al. (2021)), emphasized that the biology teaching and learning process is expected to be implemented better than other sciences because biology traces life processes that are anticipated to be stimulating and motivating to the learners. Accordingly, this study aimed to examine the effect of SPSBTA on students' scientific epistemological belief in cell biology knowledge with the necessary theories and complex concepts to believe it as scientific knowledge for students.

Hence, to apply SPSBTA, a given biology curriculum content was arranged to enable students to learn biology concepts by engaging in SPS-based activities and encouraging active participation in inquiry activities. Therefore, the learning process was gone with SPS, which involves cognitive and social skills (Susanti & Anwar, 2019). Since SPS is among the 21st-century abilities, science instructors must impart these skills to their students (Libata et al., 2023) by facilitating students to do hands-on and minds-on practical activities in the classroom or school labs (Idris et al., 2022). Besides, investigative science process skills entail activities that designate the teacher as a facilitator and allow students to create meaning that leads to scientific understanding(Cotabish et al., 2013). These skills lead students to believe that new knowledge can be constructed and knowledge can be changed with investigation. Based on this, it is possible to assume that science process skills-based inquiry learning is another student-centered method that adheres to the constructivist approach philosophy that promotes students' active participation in their learning (Ramnath, 2014).In addition, under the constructivist-oriented teaching and learning process, teachers and students are expected to view knowing as a process of constructing personally meaningful understanding and knowledge claims as uncertain.

The present study employed the following conceptual framework that shows the relationships of variables (see Figure 1) based on the reviewed practical studies and the above-discussed theoretical framework.

Figure 1

Conceptual frame work of the effect of SPSBTA on scientific epistemological beliefs



The proposed model showed the theorized relations among variables where SPSBTA appeared as an independent variable (cause) and SEB as a dependent variable (outcome). In other words, it is thought that the students' epistemological belief (dependent variable) might be affected by the SPSBTA (independent variables) and would develop after intervention.

The current study was designed to provide science-based answers to the following research questions: (1) to what extent are the epistemological beliefs of students in the treatment group affected by the implementation of SPSBTA? (2) Is there a significant difference in epistemological beliefs between male and female students after the implementation of SPSBTA?

Using different process-skill-based inquiry interventions was established in many studies. However, an efficient process skills-based approach and integrating science process skills in practical activities is vital to advance its significance. The present study is significant for learners, teachers, and other researchers. It is hoped that the SPSBTA increases students' active participation in their learning and improve their epistemological belief in biology. In addition, the findings of this study positively benefit a change in the learner's attitudes toward more effective teaching approaches such as the science process skills-based approach. Moreover, teachers are motivated to practice SPSBTA to enhance the students' SEBs in biology knowledge. In addition, it invites other researchers to investigate the effect of SPSBTA on different grade levels, topics, and intervention periods.

Methods

Study Design

The present study examined the effect of SPSBTA on scientific epistemological beliefs (SEBs). The study adopted a concurrent mixed methods approach, whereby the quasi-experimental quantitative and the qualitative data were collected simultaneously. The study used a quasi-experimental design because the research participants were not assigned randomly into groups. The researcher did not have the chance to form artificial groups; hence, intact classes were used (Campbell & Stanley, 2015). Therefore, a quasi-experimental design was deemed appropriate to utilize intact classes (Fraenkel et al., 1993). As emphasized by scholars like Edmonds and Kennedy (2016), conducting a pre-test for both groups is essential to assess groups homogeneity before the intervention. Consequently, the experimental and control groups underwent SEB measurements before and after the treatment, as illustrated in Table 1.

Table 1

Representation of the research design

Groups	Pre-test	Treatment	Post-test
Intervention	SEBQ	SPSBTA	SEBQ
Comparison group	SEBQ	Conventional method	SEBQ

Note. SEBQ: Scientific Epistemological Belief Questions; SPSBTA: Science Process Skills-Based Teaching Approach

Sampling Procedures and Sample Size

The participants of this research were all grade nine students attending government secondary schools in Woldia Town, Ethiopia. There are four governmental secondary schools in the town. Based on laboratory equipment organization, two schools were excluded. Then, the remaining two schools were randomly assigned to experimental and comparison groups to prevent contamination by minimizing communication between students from different classes**.** After having schools withal most similar laboratory infrastructures, based on the recommendations given by the school principals vis-à-vis the commitment, long period teaching experience, and educational qualification of teachers, two biology teachers together with their biology laboratory assistants and two grade nine sections they teach (one from each school) were allotted. Then, the two sections were randomly assigned as experimental and control groups using a lottery system. Identical theoretical and practical activities from chapter three, focusing on the topic "cell," were provided for both control and experimental groups. A total of 78 students- 38 (19 males and 19 females) in the experimental group and 40 (24 males and 16 females) in the comparison group participated in the study**.**

Data Collection Instruments

Scientific Epistemological Beliefs Questionnaire

This instrument was a questionnaire (SEB questionnaire) adapted from Conley et al. (2004). We utilized the SEB survey developed by Conley et al. (2004) to assess participant's epistemology**.** The questionnaire consisted of four dimensions and 26 items. Descriptions of each of the four dimensions are provided, along with examples of items, as follows:

Dimension	No. of Items	Description
Source	5	This dimension measures learners' beliefs about the source of scientific knowledge, viewing experts and external authorities as the sole sources of scientific knowledge. Example of item: Everybody must believe what scientists say.
Certainty	6	This dimension reflects learners' views in the existence of a single correct answer in science. Example of item: All questions in science have only one correct answer.
Development	6	This dimension assesses learners' beliefs regarding continual evolution of scientific subjects. Example of item: New discoveries can change what scientists consider to be correct.
Justifications	9	This dimension measures students' beliefs regarding the role of scientific experiments and how these experiments contribute to scientific knowledge. Example: Performing experiments is an important aspect of science, helping to generate new ideas about how things function. The source and certainty dimensions underwent reverse coding.

Classroom Observation

The researcher conducted classroom observations using a checklist throughout the intervention period. The observations focused on students' participation in classroom activities, the role of SPSBTA in attracting attention, enhancing their interest in learning, and using abstract concepts to construct knowledge based on their practice.

Interview

After the intervention, six voluntary students were selected for semi-structured interviews to triangulate the quantitative SB data using qualitative information. The students were asked to forward their opinions on the relevance of SPSBTA in improving their epistemological beliefs on the source, certainty, development, and justification of biological knowledge.

Validity and Reliability of the Instrument

The face validity and content validity of the SEB instrument were checked by a professor from the educational curriculum, PhD candidate colleagues, and two English language lecturers. As a result of the review, the original 26-item scale was modified to 25 items after the rejection of one item from the source dimension due to its irrelevance. The scale now includes 25 items. Furthermore, the reliability of each dimension was calculated based on piloting conducted in a school not involved in the main study. The reliability of each dimension ranges from 0.70 to 0.82, which is considered an acceptable range according to Tabachnick and Fidell (2007), as shown below in Table 2.

Table 2

Reliability coefficient for the SEB instrument

SEB dimensions	Source	Certainty	Development	Justification	Overall
Cronbach’s alpha	0.80	0.70	0.72	0.82	0.81

Data Analysis

Quantitative and qualitative analysis techniques were used to analyze the data based on the nature of the research question. The data gathered through the questionnaire was analyzed using mean, standard deviation, independent sample t-test, and one-way analysis of covariance (ANCOVA) at an alpha of 0.05 using SPSS Version 27. ANCOVA was also used to check significant post-SEB score differences between male and female students. In addition, data from observation and semi-structured interviews were also analyzed qualitatively through narration.

Ethical concern

One of the researchers held Ethical clearance from the science college, Bahir Dar University. The school principals and departments of the participating selected teachers were asked and secured permission. The researcher communicated to the participants to develop trust in the study and enlightened them on the aim of the study, possible benefits of participating in the study, and procedures. The researcher arranged a consent form that clearly showed the aim of the study, the importance of participating in the study, and the assurance of confidentiality to the participants.

Procedure of intervention processes

The intervention manuals were prepared only for the experimental group of students and teachers. The teachers' intervention manual contained the required sub-topics in the cells, objectives, SPS to be applied, and a sample lesson plan. The intervention manual was a worksheet containing the required SPS, both minds-on and hands-on SPS-based practical activities (questions), and the guidelines and procedures for the students to follow to conduct the experiments. The teaching material for the laboratory session and classroom instruction was designed based on the revised (2014/2022) syllabus, the students' textbook, the teachers' guide, and other related materials prepared by the Ministry of Education in Ethiopia. The teachers who would teach with SPSBTA were trained for two days on the SPSBTA implementation procedure, how to arrange groups, and how to facilitate students. They then practiced the SPSBTA implementation using two sample activities to gain experience.

The researcher designed eight minds-on and hands-on SPS-based student activities for the experimental group, drawing from the content of the student textbook. The sub-topics of cells used for this study included- the distinction between prokaryotes and eukaryotic cells, structural differences between plant and animal cells, the structure of plant cells, examination of animal cell structure, molecular diffusion, osmosis in plant cells, osmosis using a model animal cell, and levels of biological organization. Then, the experimental group teacher facilitated instruction using the SPSBTA for eight weeks.

In this approach, for the minds-on activities, before students read or learn the content provided in the textbook, the teacher is expected to introduce the required SPS for the daily lesson, present the daily student activity, facilitate students by encouraging responses to questions in their worksheet designed based on the daily topic and their prior knowledge, and facilitate discussion among students. On the other hand, for hands-on practical activities in the laboratory, after introducing the daily activity, required SPS, and necessary laboratory materials, the laboratory assistant facilitated students in conducting the activities themselves by applying the required SPS. At the end of these activities, the lab assistant encouraged students to discuss their results with their group members and the whole class while reporting their observations and findings. For instance, in the sub-topic 'osmosis using model animal cells', students were asked to conduct the activity using the SPS such as observation, measurement, hypothesis formation, variable identification, experimentation, data collection, conclusion drawing, and communication. To follow up on the implementation process, to give support, and to make observations, one of the researchers was physically involved with them from the beginning to the end of the data collection period. A sample of the SPS students implemented on this sub-topic is discussed as follows.

Formulating a hypothesis

The lab assistant presented the necessary laboratory materials, like the dialysis tube, sugar solution, and beaker. The question that students were asked to answer was: Is there a change in the volume of the dialysis tubes after some minutes? Why did the volume of the dialysis tubes change? Based on their previous knowledge, students formulated their hypotheses or guesses regarding the reason for the change.

Observation

This skill enabled students to explore and carefully observe the phenomena. To get evidence for their hypothesis, students carefully observed the change in volume of the dialysis tube before and after insertion into different types of solutions in the beaker.

Measuring

Students measured an equal amount of solution to fill the tubes, and after 20 minutes, they observed the change in the volume of the dialysis tubes to gather data on the volume change and to relate the observed change to its cause (the movement of water into or out of the tubes).

Collecting data, recording, and concluding

Based on the observations and measurement skills, students collected data and recorded the initial and final weights. They then formulated conclusions regarding the change in the potato weight and related this issue to the concept of osmosis.

Experimenting

Students applied different science process skills to investigate the effect of osmosis in animal cells using model cells (utilizing a dialysis tube as a cell membrane and the solution inside it as cytoplasm). This activity allowed them to explore the impact of osmosis on the cell.

Communicating

Based on the evidence gathered from the experimental activity, students discussed their results orally and in written reports with their classmates and the lab assistant. They focused on the direction of osmosis and how this activity relates to osmosis in cell membranes.

Identification of variables

The students were requested to identify the dependent, independent, and control variables for the given activity.

On the other hand, the comparison group teacher and the lab assistant utilized a conventional teaching method, which provided detailed notes before any practical work. During practical activities, the laboratory assistant demonstrated the procedure and the expected results to the students before they attempted the tasks themselves. Instead of engaging in activities that encouraged independent discovery through the application of SPS, the control group students were tasked with simply replicating what the assistant had shown. Furthermore, the lab assistant often combined multiple activities into one laboratory session, with students following instructions rather than engaging in hands-on experimentation. At the end of each lab activity, students were required to prepare a report covering the aim of the activity, the procedure, observations, and results.

The experimental and comparison groups used similar student textbooks, supporting materials, and equivalent periods and spent approximately eight weeks covering the topic. During the first week, before any intervention, both groups underwent a pre-test of the SEB questionnaire to assess their scientific epistemological beliefs. From the second to the seventh weeks, the experimental group students taught using the SPSBTA, while the comparison group followed the conventional method. Upon completion of the intervention, both groups took a post-test SEB questionnaire. In addition, there was a classroom observation during the intervention period and an interview at the end.

Results

Inferential and descriptive statistics were employed to analyze the responses gathered from the SEB questionnaire. Responses to the questionnaire were grouped into four sub-categories: source, certainty, development, and justification. Data from observations and semi-structured interviews were analyzed by narrating students' responses to the interview questions and the researcher's observations.

The Results of Pre-test Scores Analysis

The Results of Pre-SEB Overall Scores Analysis

An independent sample t-test was conducted to determine whether there was a statistically significant difference in the mean SEB scores between the comparison group (CG) and the experimental group (EG) students. As the descriptive results shown in Table 3, before the intervention, the pre-SEB scores of EG and CG students were almost similar. Levene's test result of variance (Sig = 0.173 p > 0.05) indicated no significant difference in variance between the EG and CG before the intervention. Furthermore, the t-test results showed that there was no statistically significant difference in mean scores between the two groups (mean score of EG (M = 3.83, SD = 0.33) and CG (M = 3.88, SD = 0 .33); t (76) = 0.52, p = 0.60.

Table 3

Independent sample t-test pre-SEB Overall result of groups

	Group	N	M	SD	Levene's Test for Equality of Variances		t-test for Equality of Means			
					F	Sig.	t	Df	P	MD
Overall	CG	40	3.88	0.384	1.892	0.173	0.520	76	0.604	0.042
Pre-SEB	EG	38	3.83	0.330						

Note. CG: Comparison group, EG: experimental group, M: mean, MD: mean difference, SD: Standard deviation

In addition, the independent sample t-test was conducted to analyze the pre-test scores of the two groups in the four SEB sub-dimensions. As shown in Table 4, the results of the independent sample t-tests for the four sub-dimensions– source (t = 0.136, p= 0.892, effect size d = 0.031), certainty (t = 0.811, p = 0.425, effect size d = - 0.182), development (t = 0.080, p = 0.936, effect size d = 0.018), and justification (t = -0.175, p = 0.862, effect size d = -0.040) revealed that there was no significant difference in the pre-test scores of EG and CG in any of the sub-categories.

Table 4

The independent sample t-test pre-test score of the four Dimensions of SEBs

Item	Group	N	M	SD	t	df	p	D
Source	EG	38	3.70	0.478	0.136	76	0.892	0.031
	CG	40	3.71	0.495				
Certainty	EG	38	3.93	0.400	0.811	76	0.425	-0.182
	CG	40	3.83	0.630				
Development	EG	38	3.79	0.637	0.080	76	0.936	0.018
	CG	40	3.80	0.667				
Justification	EG	38	3.96	0.434	-0.175	76	0.862	-0.040
	CG	40	3.94	0.555				

The Results of Pre-SEB Overall Scores Analysis with Gender

To determine whether a significant difference exists in the mean pre-SEB overall scores between male and female students, an independent sample-test analysis was conducted as presented and displayed in Table 5. Levene’s test for equality of variances (Sig. 0.711, p >0.05) indicated no significant difference in SEB score variances of females and males. Therefore, the t-tests were conducted by assuming equal variances. The t-test results showed that male and female students had similar pre–test SEB scores; Males (M = 3.92, SD = 0.350) and females ((M = 3.78, SD = 0.356), t (76) = 1.658, p = 0.101). This result suggests that female and male students in the two groups had similar SEB before the intervention.

Table 5

The independent samples t-test result of the overall pre-test SEBs score based on gender

	Sex	N	M	SD	Levene's Test for Equality of Variances		t-test for Equality of Means			
					F	Sig	T	df	P	D
Overall Pre-SEB	Male	43	3.92	0.350	0.13	0.71	1.65	76	0.10	.13
	Female	35	3.78	0.356						

Results of Post-test Scores Analysis

Upon examining the correlation results, there was a strong relationship between the pre-and post-test scores of the epistemological belief scale (Pearson’s’ r = 0.76). Consequently, it was necessary to calculate the covariance of the pre-test findings when comparing the post-test scores. Therefore, ANCOVA was used to compare the post-test results. Moreover, before conducting ANCOVA, one of the assumptions- normality was tested using the Shapiro-Wilk test in the EG (W (38) = 0.99, p = 0.720) and the CG (W (40) = 0.98, P=0.991) indicating that the post-test scores were normally distributed. Additionally, other assumptions like the linear relationship between the dependent variable and covariate, homogeneity of regression slope (tested with Tests of Between-Subjects Effects, $p = 0.27$, $p > 0.05$), homogeneity of variance (also tested with Levens' test, (F (1, 76) = 0.004, $p = 0.93$), and the reliable measure of the covariate, were tested, and the assumptions were not violated. Table 7 shows the details of the ANCOVA results.

Effect of Science Process Skills-Based Teaching on Overall Scientific Epistemological Belief Score

The independent sample test mean score results in Table 6 indicated that the post-SEB mean scores of EG students (M = 4.337, SD = 0.267) were higher than those of CG students (M= 4.09, SD = 0.337, t (76) = -3.502, P = 0.001).

Table 6

Independent Sample Test Result of overall Post-SEB score between groups

	Group	N	M	SD	Levene's Test for Equality of Variances		t-test for Equality of Means			
					F	Sig.	t	df	P	MD
Overall Post-test	CG	40	4.09	0.337	1.699	0.196	-3.502	76	0.001	-.242
	EG	38	4.33	0.267						

The ANCOVA result in Table 7 also revealed that the covariate (pre-test) significantly influenced the post-test (Sig. value = 0.0001, $p < 0.05$). The between-subject effect of post-test SEB in the ANCOVA table shows a statistically significant difference between experimental and comparison groups for the post-SEB after controlling for the covariate (pre-test) (F (1,75) = 53.157, p = 0.0001, Partial Eta Squared=0.415). The partial eta squared value (0.415= 41.5%) directs a high effect size, based on Cohen's (Cohen, 1988)guideline, which designates eta square values effect size values ranging from 0.14 (14%) to 1 as large effect size (Table 7). This partial eta squared value shows that 41% of post-SEB means score differences were with the implementation of SPSBTA.

Table 7

Tests of Between-Subjects Effects of the post-SEB for experimental and control groups

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.	Partial Eta Squared(η2)
Corrected Model	6.197[a]	2	3.098	114.086	0.0001	0.753
Intercept	1.350	1	1.350	49.696	0.0001	0.399
Pre-test	5.053	1	5.053	186.055	0.0001	0.713
Treatment	1.444	1	1.444	53.157	0.0001	0.415
Error	2.037	75	0.027			
Total	1390.001	78				
Corrected Total	8.233	77				

Note. α = 0.05

An independent sample t-test was conducted to analyze the difference in the post-test of the four sub-dimensions. As indicated in Table 8, a significant mean difference was observed between the experimental and control groups in two categories of SEB: source and certainty dimensions. Specifically, for the source (t = -5.385, p = < 0.0001, effect size d = -1.220) and certainty (t = -5.303, p = < 0.0001, effect size d = -1.201)sub-dimensions, the mean scores of the experimental groups (source M = 4.34, SD = 0.577 and certainty M= 4.46, SD = 0.399) were significantly higher than those of the control groups (source M = 3.73, SD = 0.397 and certainty M = 4.04, SD = 0.295). Conversely, in the other two sub-dimensions (development and justification), no significant mean difference was found in the development sub-dimension (t = 0.523, effect size d = 0.603) or justification (t = 0.020, p = 0.984, effect size d = 0.005) scores.

Table 8

Tests of Between-Subjects Effects of the post-SEB for experimental and control groups

Item	Group	N	M	SD	t	df	p	D
Source	EG	38	4.34	0.577				
	CG	40	3.73	0.397	-5.38	76	0.0001	-1.220
Certainty	EG	38	4.46	0.399				
	CG	40	4.04	0.295	-5.30	76	0.0001	-1.201
Development	EG	38	4.07	0.634				
	CG	40	4.01	0.368	0.523	76	0.603	0.120
Justification	EG	38	4.09	0.523				
	CG	40	4.08	0.342	0.020	76	0.984	0.005
Post-overall	EG	38	4.33	0.267				
	CG	40	4.09	0.337	3.50	76	0.0001	-0.793

Note. EG: Experimental group CG: Comparison group

Findings on the Gender Differential Effect of the Science Process Skills-Based Teaching Approach on Overall Post-SEBs

To explore the effect of SPSBTA on students' SEBs with gender, we analyzed the post-SEB data of both male and female students. Tables 9 and 10 display the descriptive and inferential statistics derived from ANCOVA results. The descriptive statistics reveal that the mean post-SEB score of male students (M = 4.225, SD = 0.309) appears slightly higher than that of female students (M= 4.188, SD = 0.351) (Table 9).

Table 9

Descriptive statistics of the overall post-SEB result of male and female

	Sex	N	Mean	SD	Std. Error Mean
Overall	Male	43	4.225	0.309	0.047
Post SEB	Female	35	4.188	0.351	0.059

The ANCOVA results for the post-SEB scores between genders revealed a significance value of (P = 0.250, p> 0.05). This result indicates that after controlling for the covariate (pre-test), there was no statistically significant difference in the overall post-SEB scores between female and male students (Table 9). The partial eta squared value ($\eta 2$=0.018) showed that only 1.8% of overall Post-SEB mean score variance between males and females was obtained with the implementation of SPSBTA, indicating the low effect size based on Cohen (1988). Hence, SPSBTA was not gender biased.

Table 10

Tests of Between-Subjects Effects of the Overall post-SEB for male and female students

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared (η2)
Corrected Model	4.814[a]	2	2.407	52.80	0.0001	0.585
Intercept	1.366	1	1.366	29.97	0.0001	0.286
Pre-test	4.787	1	4.787	105.01	0.0001	0.583
Gender	.061	1	0.061	1.34	0.250	0.018
Error	3.419	75	0.046			
Total	1390.001	78				
Corrected Total	8.233	77				

Note. $\alpha = 0.05$

Results from Students Interview and Observation

In this section, the interview and observation findings are presented. Regarding the interview results, we analyzed and transcribed audio recordings using content analysis. According to the interview responses, it was found that SPSBTA affected SEBs, particularly on the source and certainty of epistemological sub-dimensions.

As indicated by the mean scores in the quantitative results, students in the EG demonstrated more sophisticated SEBs overall in the post-test score and in the two sub-categories of SEB (source and certainty SEBs) compared to students in the CG. Furthermore, responses in the interviews also support the quantitative findings. For instance, when asked about their beliefs regarding the source of scientific knowledge, Student 2 from the EG responded to the question, "Have you developed the belief that everybody has to trust what scientists and science books say as a result of using SPSBTA? Why?" as follows:

> I don't always believe that the statements made by scientists and the information in science books are entirely accurate. I believe that students can observe their surroundings and pose questions. Given the appropriate resources, students can conduct experiments and discover answers to their questions. In addition, I don't consider the knowledge presented in textbooks as fixed because over time, another experimental investigation will replace that existing theory (Student 2, December 2023).

The response from student 2 indicates he holds a sophisticated belief regarding the source of knowledge. He expressed a view that did not solely rely on scientists and textbooks as sources of knowledge. In addition, he believed that students could actively construct knowledge themselves. Furthermore, he acknowledged that the content of textbooks is not fixed and could evolve based on new experimental findings, indicating a good understanding of the certainty of knowledge. His response also demonstrated a sophisticated belief in the development sub-dimension of SEB. His response described the vital role experimentation plays in knowledge evolution. This idea shows his belief enhancement regarding the nature of knowledge.

Consistent with the quantitative results, the interview response of another student in the EG also indicated a relative improvement in epistemological beliefs (EB) regarding the certainty and source of knowledge. For instance, student 4 also responded to the question- Have you developed the belief that scientific knowledge obtained by scientists' experimental results is always correct as a result of using SPSBTA? as follows:

> I disagree that scientific knowledge gained from scientists' experimental results is always correct because scientists are also human beings and thus prone to making mistakes, such as using inaccurate equipment. Therefore, other individuals, even students, can challenge that truth using the latest technology-driven equipment. Furthermore, she also believed that scientists are not the sole source of knowledge; instead, anyone interested in inquiry can contribute to generating better ideas (Student 4, December 2023).

As her statement indicated, she had sophisticated EB regarding the source and certainty epistemological belief dimensions. She stated that scientists' investigations are not always correct (certainty), and she added that individuals other than scientists can contribute to knowledge creation, demonstrating this sophistication. The interview responses of these students indicated that they had developed expert-level epistemic beliefs concerning the source and certainty dimensions.

Observation made by the researchers while students engaged in activities with SPSBTA also revealed progress in their SEB, which was evident in their responses to interview questions related to the source and certainty dimensions. The researchers observed that most students did not cease their activities after completing their tasks. Rather than stopping their activities, they were encouraged to ask questions and seek additional time from their instructor to engage in related activities. This condition allowed them to search for alternative evidence to support their findings rather than accepting what they observed in one trial or learned during the daily lesson. Moreover, the researcher noted the students' interest in engaging in debates with their classmates and teacher on various cell-related issues during class rather than accepting what they are taught or read.

Discussion

The pre-test results revealed no significant difference between the treatment and comparison groups. This showed that both groups had similar prior SEBs. However, after the implementation of SPSBTA, results showed differences between groups. Thus, the discussions below were on the research questions.

Effect of SPSBTA on Students Epistemological Beliefs during the Treatment Period

For the first research question; "To what extent is the EB of students in the EG affected during the treatment period?", the finding showed a significant difference in overall

SEB improvement and the source and certainty sub-dimensions between the groups. The quantitative and qualitative results showed that the EG students' SEBs could lead to a more sophisticated SEB level than the CG in the source and certainty SEB dimensions. However, there was no significant SEB change in the development and justification sub-dimensions. The findings of the current study are consistent with other findings that showed the improvement of SEBs after the implementation of different inquiry-based practical activities (Belay et al., 2023; Conley et al., 2004; Shi et al., 2020; Zhao et al., 2021). For instance, Zhao et al. (2021) results showed the positive effect of POE on two dimensions (source and certainty) in the EG. Therefore, SPSBTA improved the source and certainty of SEB sub-dimensions of ninth graders.

In contrast, the current study result opposed the studies in the literature that applied inquiry-based method of teaching in lower grade level (elementary school) students but could not provide a significant overall SEB change (Çalışkan, 2004; Caukin, 2010; Wu et al., 2021). This might be due to the countries' context difference (Gilbert et al., 2016) and the grade level difference (Cano, 2005; Kurt, 2009; Ongowo, 2022). For instance, the latest study by Ongowo (2022) found that grade 12 students had greater EB mean scores in all sub-dimensions than grade nine students, and this researcher indicated that as the grade level increased, instructional experiences that the learners were exposed to could improve the EB. This result might be related to the instructional technique practiced during the teaching-learning process.

The change in epistemological beliefs observed in the EG may be due to the nature of SPSBTA, which encourages hands-on inquiry and practical activities by applying different SPS. This condition enables students to construct ideas based on their practical observations, measurements, and experiments in the activities rather than focusing on directly accepting what the books and teachers demonstrate. Several processes and skills in science allow us to create and expand our knowledge (Council, 2012).

Thus, the science learning process emphasizes providing direct learning practices for learners to heartily realize natural phenomena, science principles, and concepts through SPS (Indriana et al., 2021; Ramdiah & Royani, 2019). Besides, the literature indicates that hands-on activities can shape students' opinions about science and scientific knowledge (Hong et al., 2016). However, with the application of SPSBTA practical activities, SEBs was not significantly improved in the development and justification sub-dimensions. The present result supports that students' SEBs can be at different levels of sophistication for different sub-dimensions (Yenice & Özden, 2013). This result is similar to the study by (Caukin, 2010; Conley et al., 2004; Wu & Wu, 2011). For example, Conley et al. (2004) confirmed that even though students taught using an inquiry-based approach, their epistemological assumptions regarding the development and justification of knowledge did not improve. The reason for non-significant improvement in these two dimensions might be the shortage of time for discussion. Engaging in hands-on tasks that need critical observation and measurement activities takes more time, which limits students' opportunities to discuss, collaborate, and exchange ideas with one another and with their teachers about their practical activities and associated scientific topics. This challenge could be one reason for the lack of significant improvement in the development and justification dimensions. The development and justification dimensions are more advanced than the source and certainty dimensions (Hofer

& Pintrich, 1997). Hence, it might be challenging to improve the development and justification dimensions.

In addition, some researchers in the literature, such as Kızkapan and Bektaş (2021) and Muis and Duffy (2013), stated that it is hard to change students' EB in all dimensions. One of these difficulties was the intervention time duration; a long period is necessary for the proper transition in epistemological views. Hence, as scholars emphasized, students may not be sufficiently changed in all sub-dimensions of EB from persistent non-expert ideas and viewpoints by a single intervention on a particular issue. For instance, Kızkapan and Bektaş (2021) showed that a six-week intervention was insufficient to change the groups' scores on EB. Furthermore, according to Muis and Duffy (2013), students must be exposed to material that causes them to question their preexisting ideas for their epistemological beliefs to change. However, in the comparison group, there was no significant change in the dimensions of SEBs. This lack of change occurred because students did not engage in hands-on practical activities.

Gender Differential Effect of SPSBTA on Students Scientific Epistemological Belief

The second finding pertained to the other research question: Is there a significant SEB mean score difference between male and female secondary school students participating in SPSBTA? The result of the study regarding this research question indicated that the implementation of SPSBTA did not result in a significant difference in overall SEB mean scores between male and female students. Although the post-SEB mean score for male students (M = 4.225, SD = 0.30889) was higher than that for their female counterparts (M = 4.188, SD = 0.351), the difference in mean scores was not statistically significant, as indicated by the ANCOVA result (see Table 10).

The result of the current study was consistent with other findings (Conley et al., 2004; Korom et al., 2023; Yakisan & Karasah, 2016). For instance, Yakisan and Karasah (2016) found that female students had a higher mean epistemological beliefs score than male students, but the difference was not significant. Similarly, (Korom et al., 2023) showed that gender does not affect epistemological belief. It may be that other factors, such as student- or teacher-related factors, are more significant in the development of EB. Based on our result and other findings, it is possible to conclude that SPSBTA does not yield a significant EB mean score difference between males and females. Instead, it helps male and female students comparably. However, the current finding refuted other findings (Belet & Guven, 2011; Chai et al., 2006; Er, 2013).

In the Ethiopian cultural context, females mostly lack the opportunity to openly argue and reflect their point of views. Hence, males are fortified to be experts, whereas females are pressed to be reluctant at home and school. However, the present study results have shown that male and female students had almost equal scientific epistemological beliefs. This result might be due to the nature of SPSBTA-enabled male and female students to participate in their learning equally, and it may also relate to the Ethiopian government's decisions to increase female participation in schools. Thus, we suggest that, although some differed from our findings, appropriate and repeated implementation of the SPS-based teaching approach can positively affect SEB improvement. The suggestion also includes gender differences that have no statistically significant impact on SEB. The difference in findings between the present study and other studies may be due to the school context and methodological differences. Generally, this study fills literature gaps related to emphasizing the relationship between SPSBTA and SEBs, and it also sheds light on the realization of SPSBTA in Ethiopia.

Conclusions and Recommendations

Based on the findings, the study concluded that the implementation of SPSBTA enabled students to enhance their overall SEBs. Specifically, students demonstrated improvement in the source and certainty sub-categories of SEBs. Remarkably, qualitative data from interviews and observations provided additional insights into the impact of SPSBTA on students' SEBs. In general, this study concluded that engaging students in hands-on practical activities that integrate SPS and lessons promoting active participation enhances understanding of how scientific knowledge can be constructed. The current finding emphasized that SPSBTA instruction is crucial for creating a more student-centered teaching-learning environment and empowering students to be active participants in their classroom. Implementing SPSBTA also improved SEB by encouraging students to interact with scientific concepts based on the results of hands-on activities in the learning process. This condition, in turn, fosters the development of expert-like beliefs in scientific knowledge among students.

Based on the findings of this study, the researchers provide the following recommendations for practice and further research. In practice, teachers should create conducive learning conditions that enable students to engage in practical activities, stimulating epistemic competence by encouraging students to discuss their practical activity results and initiate knowledge construction. Additionally, science teachers should consider including SPSBTA in science courses to improve students' SEBs. SPSBTA strongly emphasizes experiential, inquiry-based learning opportunities that foster critical thinking, problem-solving abilities, and an active understanding of scientific ideas. It is conceivable to suggest that a short-period intervention in one subject area may not suffice to improve SEBs to an expert-like level. In terms of research, other studies might explore the long-term effects of SPSBTA on SEB across different grade levels and educational contexts and investigate students’ SEB improvement, focusing on the development and justification of sub-dimensions. Additionally, investigating the impact of SPSBTA on other aspects of students' learning, such as scientific literacy or problem-solving skills, could provide a more comprehensive understanding of its benefits.

Limitations of the study

While the study provides valuable insights, it also highlights some limitations. One limitation was the purposive selection of secondary schools and the small sample size, which might limit the generalization of the findings to a large population. The second limitation was related to the certainty of SPSBTA for other units or subjects, as the present study only implemented SPSBTA for one unit of teaching.

Declaration of Conflicting Interests

No potential conflict of interest is declared by the authors.

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