Effectiveness of Collaborative Constructivist Strategies to Minimize Gaps in Students' Understanding of Biological Concepts

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Abstract—This study aimed to test how the collaborative constructivist learning strategies can reduce the gap in students' understanding of biological concepts, compared to Novick's constructivist strategies, and student team achievement divisions (STAD) collaborative strategies. Six classes of tenth graders consisted of 12 upper and lower academic students each were randomly placed into three learning strategy treatment groups: Collaborative constructivist, Novick's constructivist, and STAD. Students were given essay to tests their biological concepts understanding before and after treatment. The difference in students' understanding and the gaps in understanding between UA and LA students were analyzed. The results showed no difference in students' understanding if treated with Novick's and collaborative constructivist. Differences in students' understanding were found in the treatment of STAD. Students' understanding was higher if treated with collaborative constructivist and Novick's constructivist than STAD. Collaborative constructivist strategies can reduce the gap in students' understanding and optimize gain in students' understanding to the other two strategies.

Keywords—conceptual understanding, constructivist, collaborative

1 Introduction

Bibliographic studies showed many studies have examined the effectiveness of Biology learning strategies on students' conceptual understanding. But only a small number of them focused on how to minimize the gap in understanding between upper academic students (UA) and lower-academic students (LA) [1]. Many studies showed various learning strategies affect students' understanding. But when observed, they were always distributed in a normal curve consisting of students with high, medium, and low conceptual understanding based on variations in students' academic abilities[2]–[4]. Learning strategies do not necessarily reduce the gaps in students' conceptual understanding [1], [5]. Innovative biology learning strategies that can improve students' conceptual understanding and reducing the gap in students' conceptual understanding are needed.

Understanding the concepts is one goal of learning [6]. Conceptual understanding is the ability to re-explain what has been learned [7]. Indicators of concept understanding include the ability to restate the learned concepts, evaluate concept attributes, apply concepts, present concepts, and elaborate on various concepts [6], [8]. Students' conceptual understanding can be categorized into four: no understanding (NU), alternative conceptions (AC), partial understanding (PU), and sound understanding (SU). NU is characterized by the absence of answers, no-idea answers, or irrelevant answers. The AC is characterized by the attempt to explain the concept but not following the established scientific conception. The PU is characterized by responses that contain at least one component of scientific conception. The SU is characterized by responses that are entirely following scientific conceptions [8].

Conceptual understanding is the result of a student's active knowledge construction while interacting with the learning environment [9], [10]. Conceptual understanding is also gained from the interaction between the initial schema and knowledge with the new ones [11], [12]. Schema is the mental structure that will adapt to the learning experience [13]. Interaction between the initial schemas with the new ones causes an imbalance in the cognitive structure [14]–[16]. The assimilation and accommodation led to the formation of new schemes [17]. Assimilation is a cognitive process by which old schemes are integrated with new perceptions, concepts, or experiences [14]. Assimilation does not cause schematic changes but develops new schematics [18]. Accommodation forms new scheme or changing the old scheme, due to new experiences or concepts that cannot be assimilated into the old scheme. Accommodation also occurred if new concepts do not match with the old ones [15], [19], [20]. Schemata resulting from assimilation and accommodation are the representation of the conceptual understanding [21].

One of the learning strategies developed from constructivism theory and widely used in classroom learning is Novick's constructivist strategy [15], [22]. It consists of three stages: Stage 1: Exposing alternative framework, creating cognitive conflict, and encouraging cognitive accommodation. Students are activated schematically initially relating to the new knowledge being learned. Stage 2: Students' initial schemes are conflicted with new phenomena and concepts, resulting in schematic imbalances in their cognitive structure. Stage 3: students undertake assimilation and accommodation activities until a new schematic (new concept) is formed on their cognitive structures [15], [22], [23]. Many studies convince the application of Novick's constructivist strategies to influence the understanding of student concepts [22], [23].

Many studies concluded that students' conceptual understanding was correlated with students' stage of cognitive development [16]. Students who have reached the formal operational thinking were easier to understand concepts [10], [24]. Unfortunately, many studies showed that students' biological age does not always align with the ideal stage of cognitive development. Not all students can reach the formal operational thinking stage when they reach adolescence [24]. It can be concluded that this phenomenon causes the gap in conceptual understanding between UA and LA students. Therefore, constructivist learning strategies in the classroom with diverse students' cognitive development may cause a gap in conceptual understanding between UA and LA students.

If students are distributed normally based on their talents, then given the same quality of learning and study time in the classroom, their conceptual understanding will be distributed based on their talents [25]. Talented students (UA students) have a higher conceptual understanding than less talented ones (LA students) [25], [26]. However, many studies concluded that talent is not an index of abilities but rather a measure of learning rate [25], [27]. Students with high talent need a shorter study time to understand concepts than students who have low talent. Students with low talent can understand concepts as high-talented students if given study time as needed [26], [28], [29]. Therefore, to minimize the gap in students' conceptual understanding, study time must be allocated according to the students' needs [25].

The problem is, in Indonesian schools students are distributed based on their biological age, and then they are given the same quality of learning and study time, thus the gaps in students' learning outcomes are inevitable [30] . In addition, some studies concluded that the proper study time allocation does not necessarily improve students' understanding [31], [32]. LA students at some point have learning difficulties that they are unable to complete. Vygotsky calls this the actual zone [20]. To help LA students pass through the actual zone to the proximal development zone, scaffolding from others is needed, such as from teachers and friends who know better [12], [31].

Learning strategies that can facilitate scaffolding well are collaborative-based [33]–[35]. The collaborative learning strategy ensures UA students provide scaffolding to LA students, and they also get scaffolding from teachers [30]. Collaborative strategies can facilitate students to learn according to their time needs [33]. Some research shows that collaborative strategies can reduce the gap in students' understanding between UA and LA students [36]. Our bibliometric study concluded that one of the most widely used collaborative strategies in research is STAD. STAD consists of the following steps: (1) Teacher presentation: teachers explain the concepts that students will learn. (2) Collaborative group discussion: students discuss the assignments in collaborative groups. (3) Class presentation: student groups present their results in class seminars. (4) Individual test: students are given individual tests to measure their mastery of concepts. (5) Team recognition: recognition of student groups for their collaborative work. Some studies concluded that STAD can reduce the gap in students' learning outcomes [32], [37].

Some studies stated that STAD is less constructivist because teachers still position themselves as learning centers and sources of information rather than as facilitators [32]. Learning activities in STAD starts from the transfer of knowledge by teachers followed by discussions on the application of knowledge by students in collaborative groups [32], [37], [38]. This learning is widely assessed by constructivists as less meaningful learning, thus potentially leading to low-level understanding, retention, and students' learning outcomes [13]. Some empirical research corroborates this opinion [32], [38].

To improve students' concept mastery and minimize the gap in students' understanding, collaborative constructivist learning strategies were developed. This strategy was developed based on Piaget's constructivism theory which carries the concepts of schematics, assimilation, and accommodation. It also accommodates Vygotsky's constructivism theory that carries the concept of actual zones, potential zones, proximal development zones, and scaffolding [12], [20]. Collaborative constructivist strategy consists of six stages: (1) Collaborative team formation and learning contracts: students are formed into heterogeneous groups based on academic ability and are explained about the rules of collaborative work. (2) Initial schematic activation: students' initial schemes are activated by teachers, (3) Creation of cognitive conflicts: initial schematics are to be conflicted with the new phenomena and concepts. (4) Concept formation: students construct new concepts in collaborative groups. (5) Class presentation: students present the results of their concept construction in a class seminar. (6) Individual tests and group recognition: students take tests and group recognition. However, whether the collaborative constructivist learning strategies will improve students' understanding and reducing the gap in students' conceptual understanding compared to Novick and STAD will be answered in this research.

Based on the explanations above, the questions to be answered in this study were as follows: (1) Are there any differences in conceptual understanding between students learning using collaborative, constructivist Novick, and STAD strategies? (2) Are there any differences in students' conceptual understanding between UA and LA students? (3) What is the most optimal strategy to improve students' conceptual while reducing the gap in understanding between UA and LA students?

2 Research methodology

2.1 General background

This was a quasi-experiment with a 3 × 2 factorial design. Six classes of tenth graders (12 UA and LA students) were randomly placed into three strategy treatment groups: collaborative constructivist, Novick constructivist, and STAD. The research was conducted at one of the high schools in Karanganyar, Indonesia. The Animalia were concepts to be learned by students. Treatments were carried out in six meetings, 2 × 45 minutes each. Before and after treatment students were given tests to assess their understanding. P-rates and the homogeneous samples were used to control the extraneous variables before and during treatment. Before treatment, partner teachers were trained to implement those learning strategies. Training ensure accuracy and consistency in implementing learning strategies. The design was visualized in Table 1.

Table 1. Factorial design group 3 × 2

Factor B: Students' Academic Ability	**Factor A: Learning Strategy**		
	Collaborative Constructivist (A1)	***Constructivist Novick (A2)***	***Collaborative STAD (A3)***
Upper Academic (B1)	A1 B1	A2 B1	A3 B1
Lower Academic (B2)	A1 B2	A2 B2	A3 B2

2.2 Participans

The population was all tenth-grade students in one of the high schools in Karanganyar, Indonesia (266 students) distributed in seven classes. Each class contains 38 students. Six classes were randomly assigned to participate in the study. In each class, upper and lower academic students were selected. Students were categorized based on their report grades in the previous semester. Thirty percent of students above and below averages were designated as the sample of UA and LA group respectively. Thus, in each class 12 UA and 12 LA students were selected. Six classes were chosen in this research. Thus, the total participants were 144 students consisting of 72 UA and 72 LA students. All students and teachers have committed their consents.

2.3 Instrument and procedures

Students' conceptual understanding was assessed using an essay test. Indicators of conceptual understanding include the ability to restate concepts, evaluate concept attributes, apply concepts, present concepts, and elaborate between concepts [8]. To maintain logical validity, the rubrics were arranged concerning the topics and concept constructions. The test was equipped with a rubric to maintain objectivity. The validity was tested by three experts who assessed the accuracy of the content and the concept construction. The reliability was measured 0.78 on Cronbach's alpha test (high). Treatment procedures were described as follows.

Collaborative constructivist. Stage 1: Heterogeneous groups were formed based on variations in students' academic abilities. Students were explained that they were assessed for the development of their achievements. Students' achievements were used as the basis for the group ranking. The development of individual achievements was measured from the difference in pretest and post-test. The results were used to determine students' development scores. For example, if the students get a perfect score, then their development score is 30 points, if the student obtains 1–10 points above the initial score then the development score is 15 points. The accumulation of individual development scores becomes the basis for determining the achievements of groups that were categorized as good, great, and super. Stage 2: Students' initial schematic students related to the concepts to be studied were activated. For example, on the sub-topic of Aves, students' initial knowledge of Aves as animals that can fly, beaked, and two-legged. Stage 3: Students' initial schematics were conflicted with new phenomena. For example, students were shown to the various animals such as butterflies, dragonflies, bats as animals that can fly but are not called Aves, cassowaries cannot fly but are called Aves, humans are two-legged but not called Aves, Platypus are beaked but not called Aves. This cognitive conflict triggers imbalances in students' cognitive structures. Stage 4: Students in groups perform concept construction through direct observation, literature studies, and video observations. Stage 5: Students present the results of their construction at class seminars. Stage 6: Tests were conducted to assess students' conceptual understanding and calculate individual developmental scores and groups reward as described in Stage1.

Novick's Constructivist. Stage 1: Students' initial schematics were activated. Stage 2: Cognitive conflicts were initiated. Stage 3: Students in groups construct knowledge by conducting direct observations, literature studies, and video observation, followed by class presentations. Stage 4: Reinforcement and correction. Stage 6: Post-test.

Collaborative STAD. Stage 1: Concepts of the topic to be studied were explained by teachers. Stage 2: Heterogeneous groups were formed based on students' academic ability, and the rules were explained. Students' groups were assigned to discuss problems related to the topic. Stage 3: Students present the results of their discussions in class. Stage 4: Post-test, individual developmental scores were calculated, and group's reward was given.

2.4 Data analysis

Data were analyzed using ANCOVA with pre-test scores as covariate. Before ANCOVA, data normality tests, and variant homogeneity tests were performed. Data normality was tested using Kolmogorov Smirnov test. The results obtained the pre-test data of 0.200 and post-test 0.198 or greater than the α: 0.05; thus the data have a normal distribution. Variant homogeneity was tested using Levene's test. The results obtained the value of 0.254 or greater than α: 0.05 so the variants between data groups were homogeneous. Significance differences in variable average values were tested using the Tukey post-hoc test. Statistical calculations were done with IBM SPSS at a sig. level of 0.05.

3 Research results

ANCOVA was used to test the students' biological concepts understanding based on three treatments of learning strategies and academic ability and their interactions. The results were visualized in Table 2.

Table 2. Influence of strategy, academic, and interaction on understanding of concepts

Source	Sum of Squares	dF	Mean Square	F	Sig.
Corrected Model	1908.328	6	318.055	11.204	.000
Intercept	2349.895	1	2349.895	82.780	.000
Pretest	3.114	1	3.114	.110	.742
Learning strategy	1472.591	2	736.295	25.938	.000
Academic	325.495	1	325.495	11.466	.001
Learning strategy * Academic	96.413	2	48.207	1.698	.191
Error	1845.173	65	28.387		
Total	310906.432	72			
Corrected Total	3753.501	71			

a. R Squared = .508 (Adjusted R Squared = .463)

The results showed that the learning strategy got the sig. value of .000 < α: .050. It was concluded that there was a significant difference in students' understanding due to different treatments in learning strategies. The post-hoc test was also done and visualized in Table 3.

Table 3. Post-hoc tests of differences in students' biological concepts understanding

Learning strategies	Pre-test	Post-test	Δ	Mean	Notations
STAD	25.005	59.234	34.229	59.196	a
Novick's Constructivist	26.414	66.649	40.235	66.739	b
Collaborative-Constructivist	24.955	70.059	45.104	70.009	b

The results showed that students who were treated with collaborative constructivist strategies and Novick constructivists have no significant differences in their conceptual (indicated by notation b). But they have significant differences from students who were given STAD (indicated by notation a). Conceptual understanding treated with Novick's and collaborative constructivist strategies was significantly higher than students who were given STAD (notations a and b).

ANCOVA results also showed that the students' academic ability got the sig. Value of .001 <α: .050. It was concluded that there was a difference in students' biological concepts understanding between UA and LA students. The corrected mean score of UA students was 67.510, higher than LA students' (63.119). The difference in understanding of biological concepts between UA and LA students was visualized in Table 4.

Table 4. Differences in understanding of biological concepts between UA and LA students

Academic Abilities	Pre-test	Post-test	Δ	Corrected Mean
Upper Academic (UA)	26.029	67.457	41.428	67.510
Lower Academic (LA)	24.290	63.173	38.883	63.119

ANCOVA results also showed that the interactions between learning strategies and students' academic ability got sig. Value of .191> α: .005. Thus, there were no interactions between learning strategies and students' academic ability toward students' biological concepts understanding. A post-hoc test was also done and the results were visualized in Table 5.

Table 5. Differences in students' concepts understanding between UA and LA students

Learning strategy	Academic	Pre-test	Post-test	Δ	Mean	Notations
STAD	LA	24.401	57.680	33.279	57.576	a
STAD	UA	25.709	60.793	35.084	60.815	a
Novick's Constructivist	LA	26.362	62.823	36.461	62.907	ab
Collaborative Constructivist	LA	25.912	69,017	43.105	68.874	bc
Novick's Constructivist	UA	26.467	70.476	44.009	70.572	c
Collaborative Constructivist	UA	23,998	71,100	47.102	71.143	c

The results showed no significant differences in students' biological concepts understanding between UA and LA students treated with collaborative constructivist strategy and UA students treated with Novick constructivist strategy (notation c). There were no significant differences in students' biological concepts understanding between LA students treated with collaborative and LA students treated with Novick's Constructivist (notation b). There was a difference in students' biological concepts understanding between UA and LA students treated with Novick's strategy (notation c and b). There was no difference in students' biological concepts understanding between LA students treated with Novick strategy and UA and LA students treated with STAD (notation a). There was a difference in students' biological concepts understanding between UA and LA students treated with collaborative constructivist strategy and AA students treated with Novick's and UA and LA students treated with STAD (notation c and a). There were no differences in students' biological concepts understanding between UA and LA students treated with STAD (notation a).

Table 5 showed that biological concepts of UA and LA students treated with collaborative constructivist strategy and AA students treated with Novick were highest compared to LA students treated with Novick's constructivist and UA and LA students treated with STAD. The lowest gains in concepts understanding were experienced by UA and LA students treated with STAD. These findings showed that: (1) Collaborative constructivist and STAD were proven to minimize the gaps in biological concepts understanding between UA and LA students. (2) Novick's constructivism causes gaps in biological concepts understanding in UA and LA students. (3) Biological concepts understanding of UA and LA students treated with collaborative constructivist strategy and Novick's were higher than the students with STAD. (4) Collaborative constructivist strategies were proven to improve the students' biological concepts understanding, and Novick's constructionist can reduce the gap in students' biological concepts understanding between UA and LA students

4 Discussion

The results showed differences in biological concepts understanding between students who were treated with collaborative constructivist strategies, Novick's constructivists, and STAD. The lowest score in biological concepts understanding was found in students treated with STAD. They were in line with constructivism theory which states the concept should be constructed by students independently [11]. In concept building, students must match the perception and experience of the object studied with their initial schematic in their cognitive structures. If the perception and experience were in line with their initial schematic, then they will assimilate them into their initial schematic into a more developed schematic [11], [16], [39]. If their initial schematics did not correspond to the new perceptions and experiences, then there will be an imbalance in their cognitive structure. Students must decide whether the initial schemata need to be replaced with the new ones or the schematic is maintained by the student. If the initial schematics were to be replaced, then students will gain an understanding of the new concepts [10], [13], [14].

Novick's collaborative and constructivist learning steps were developed by accommodating key concepts in constructivism theory [15], [22]. The teachers position themselves as facilitators that ensure the students' concept construction process runs optimally. Both strategies begin with the activation of the students' initial schematic related to the object studied, then continued with the teachers presenting cognitive conflicts such as new perceptions and experiences that contradict the students' initial schematic. Cognitive imbalances are to be expected to arise. Then, learning activities continued with the construction of new knowledge through assimilation and accommodation by students [15], [23]. Novick's collaborative and constructivist strategies ensure more meaningful learning. Many studies concluded that constructivist-based learning strategies were effective in improving the students' conceptual understanding [13]. In STAD, learning started from the presentation of concepts by teachers, followed by collaborative group discussions. STAD has a lower level of constructivism compared to the other two strategies [1], [32]. STAD views that knowledge can be replicated from the teachers' minds to the students'. On the other hand, many studies convinced teacher-centered learnings were less effective at improving students' conceptual understanding [13].

The results also showed differences in biological concepts understanding between UA and LA students. Variations in students' academic abilities occurred because they were not always a linear correlation between students' biological age of students with their mental ages. Eleven-year-old students or above were not necessarily can think at the formal operations level, even more, students have not reached it [24]. Distributing students in a uniform biological age with diverse cognitive developments resulted in stratifications of students' academic abilities: Upper (UA), Middle (MA), and Lower (LA) academic students [26].

Students' biological concepts understandings were influenced by internal and external factors. Internal factors come from within the student such as talent, perseverance, and cognitive capacity. External factors come from outside such as the quality of teachers and the learning process, and the time allocation given to students [25], [27]. If the student is distributed in a normal curve on their internal factors then given the same treatment on their external factors, then their understanding will follow the normal curve distribution according to their talent [25]. If students were distributed normally in talent, perseverance, the cognitive capacity, then given the same quality of learning and study time, their conceptual understanding will follow the distribution of their talents and will be stratified into UA, MA, and LA. Those explanations confirmed various research findings that significant differences in concepts understanding between UA and LA students were observed.

The results also showed that collaborative constructivist strategies can minimize the gap in students' biological concepts understanding that not present in Novick's constructivist, and can improve students' biological concepts understanding that cannot be found in STAD. The collaborative constructivist learning strategy can improve students' conceptual understanding and reduce the gap between UA and LA students compared to the other two strategies.

Collaborative constructivist strategies such as Novick's constructivist strategies were developed based on constructivism, and have been shown to improve the students' conceptual understanding [11], [40]. This study's findings showed that the understanding of students who were treated with these two strategies was highest than students treated with STAD. UA and LA students who were treated with collaborative constructivist strategies have no significant differences in their conceptual understanding. UA and LA students treated with Novick's have significant differences in their conceptual understanding. These findings indicated that although both strategies are constructivist-based, they have different characters. The collaborative-constructivist strategy was developed by the author by integrating Piaget's constructivism theory and Vigotsky's theory of collaborative learning. Collaborative activities are considered able to minimize the gap in conceptual understanding between UA and LA students. Academic abilities (talent) are not an index of students' abilities but rather a measure of learning rate [25]. UA students take a shorter time than LA students in understanding the same concept. If LA students were given study time as they needed, then they will have the same conceptual understanding as UA students [25], [38]. Collaborative work provides the flexibility of study time according to the diversity of students' time needs. Collaborative work facilitates LA students to go through their actual zone to their proximal development zone with proper scaffolding [18], [33], [41]. Collaborative characters can minimize the gap in conceptual understanding between UA and LA students.

The collaborative-constructivist strategy has both constructivist and collaborative characters so it can improve the students' conceptual understanding and reduce the gap in conceptual understanding between UA and LA students compared to Novick or STAD. Novick's constructivist strategy was developed based on the theory of competitive personal constructivism [38]. Despite working in groups, students will competing to be the best, thus scaffolding does not run optimally. Group formation and group work rules on Novick's constructivist strategy are not as designed to facilitate proper scaffolding as in collaborative-constructivist strategies.

Novick's constructivist strategy does not accommodate students' diverse study time needs and is less able to facilitate students entering their proximal development zone. As the results, study findings suggested that Novick's constructivist strategy resulted in a gap in conceptual understanding between UA and LA students, although overall students' conceptual understanding was no different from collaborative-constructivist strategy.

STAD was developed based on tabula rasa theory and collaborative learning theory [32]. The tabula theory believes that concepts can be replicated from the teachers' minds to the students'. The first phase of STAD was the explanation of concepts by teachers followed by collaborative discussions by students about the issue related to the topics [42]. STAD has considered still as teacher-centered learning [32], [38]. Many studies concluded that teacher-centered learning strategies lead to low students' conceptual understanding [13]. Collaborative character in the STAD can facilitate the diversity of students' learning time needs, and ensure scaffolding runs well so that students can enter their proximal development zone. The study findings showed that STAD resulting the lowest gain in students' biological concepts understanding compared to the other two strategies. But this strategy can reduce the gap in conceptual understanding between UA and LA students.

5 Conclusions and implications

This research provided strong evidence that constructivist-based learning strategies such as Novick's constructivist and collaborative-constructivist strategies were effective in enhancing students' understanding of biological concepts. The study findings showed that there were differences in conceptual understanding between students treated with collaborative-constructivist and Novick strategies compared to students treated with STAD. STAD was considered as a less constructivist learning strategy. The results confirmed that collaborative learning can reduce the gap in conceptual understanding between UA and LA students. Effective scaffolding on collaborative group work can usher LA students into their proximal development zone. The results showed that the collaborative constructivist and STAD can reduce the gap in conceptual understanding between UA and LA students. The results proved that the integration of constructivist and collaborative characters in optimal learning strategies improves the students' conceptual understanding and reduces the gap in conceptual understanding between students. Teachers were advised to combine constructivist strategies with collaborative strategies. Future research should modify competitive constructivist strategies by incorporating potential collaborative characters.

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