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The use of clay modeling to increase high school biology vocabulary learning

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Abstract
Purpose – The paper explored the benefits as well as the concerns of vocabulary learning with clay modeling in terms of practical and pedagogical implications for creating positive learning experiences.
Design/methodology/approach – A mixed-methods design was conducted to examine the effectiveness of vocabulary learning with clay modeling practices in lower socioeconomic status schools.
Findings – Although test results showed no statistically significant differences between the groups, the clay modeling group did improve vocabulary acquisition similar to the sentence writing group. The students were actively engaged with hands-on activities using the clay and also demonstrated positive emotional, behavioral and physical experiences.
Research limitations/implications – The addition of the clay modeling provided an opportunity for kinesthetic learning but created a high extraneous cognitive load with the challenges incurred through the use of clay.
Practical implications – The challenges can be reduced by 1) adopting appropriate instructional strategies to design and implement effective clay modeling activities for students and teachers, 2) providing training or professional workshop development for teachers and 3) ongoing practical support and assistance for students.
Social implications – Exploring the use of kinesthetic instructional practice at the high school level may prove beneficial since clay modeling is frequently used effectively at lower grade levels.
Originality/value – The current study explores the added value of clay modeling for high school students' biology vocabulary learning in a lower socioeconomic status school from practical and pedagogical perspectives.

Keywords Clay modeling, Vocabulary learning, Academic achievements, High school, Biology
Paper type Research paper

Introduction
Vocabulary knowledge is essential for reading comprehension at all levels of education (Hsueh-Chao *et al.*, 2000). It is one of the key indicators of student success on standardized tests in schools (Sprenger, 2013). Teachers have implemented various learning strategies (e.g. word detective and wide reading) to improve students' vocabulary learning in the classroom.

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While teachers apply new learning strategies to help students learn better, however, some students are still challenged to engage and learn vocabulary (Beck *et al.*, 2013).

Researchers have focused on individual differences in the learning process, building on Sadoski and Allan's (2013) dual coding theory and Fleming and Mills (1992) and Fleming (2006)'s visual, aural/auditory, read/write, kinesthetic (VARK) learning styles. The studies of various sensory modalities for information processing indicate that individual learners have different preferred learning styles (Pritchard, 2014). For example, auditory learners prefer to learn by listening, while kinesthetic learners prefer to learn by doing. Heilman *et al.* (1990) suggested a multi-sensory approach to vocabulary teaching and learning since vocabulary words can be learned in different sensory forms that address word meaning, recognition, phonics and even spelling (Herman, 2021). Although some students rely heavily on one of the learning styles, most are able to learn vocabulary through a multi-sensory approach.

Recently, innovative strategies, such as graphic organizers, memory games, team activities and even technology, are routinely used in elementary schools to help young students master vocabulary. However, many classroom teachers face challenges due to limited resources and support (e.g. training, professional workshop development or technical assistance) when incorporating appropriate strategies into their daily lessons (Kim and Downey, 2016, Kim *et al.*, 2017). At the secondary school level, direct vocabulary instruction is not included in detail in classes. In many cases, teachers merely introduce their subject-related vocabulary or leave students to discover subject-related vocabulary through individual investigation or study of textbook sources (Marzano, 2010). Students in lower socioeconomic status schools are often expected to master the definitions and usage of new vocabulary words with limited resources and support.

In this study, we explored the benefits as well as the concerns of vocabulary learning with clay modeling in terms of practical and pedagogical implications for creating positive learning experiences. The study was guided by the following research questions:

RQ1. How does clay modeling in high school biology classes affect students' vocabulary learning?

RQ2. What are participants' suggestions to improve learning experiences with clay modeling?

Background

This study is built upon Dale's (1947) contrived experience, Hubbard's (1996) approach to the use of clay and Sadoski and Allan's (2013) dual coding theory to improve high school biology vocabulary acquisition. For example, we adopted Dale's contrived experience as the central focus that justifies the time and effort in applying kinesthetic learning activity with clay. For the dual coding theory perspective, we used the visual (Moody *et al.*, 2018) and kinesthetic aspects to enhance traditional classroom instruction where vocabulary is usually taught by teacher-led instruction that focuses more on auditory or visual learning modalities. Specifically, we explored whether adding kinesthetic experiences with clay can help students learn and retain new words better than visual or verbal clues alone.

The concept of a cell is abstract and challenging to visualize without viewing a cell through a microscope. Adding kinesthetic activity with clay creates more real experiences than simply reading instructional material. The scientific concepts and principles can be understood and retained more accurately through the incorporation of kinesthetic activity. Similarly, students would develop better vocabulary knowledge through hands-on experiences than from reading the textbooks. For example, students are more likely to recall the name of the test tube or beaker when they are participating in a science lab experiment that includes the use of test tubes or beakers.

Using art activities with clay has proven to be successful in developing young students' basic mathematics skills (Chumark and Puncrebutr, 2016) and science vocabulary (House, 2007) by observing, classifying and comparing clay objects. Dubey and Rule (2007) provided an example of clay science activities to enhance middle school students' learning. At the college level, Kooloos *et al.* (2014) employed clay modeling to enhance three-dimensional understanding of anatomy. The current study explores the added value of clay modeling for high school students' biology vocabulary learning in a lower socioeconomic status school from practical and pedagogical perspectives.

Method

A mixed-methods design study (Creswell and Plano Clark, 2011) was conducted to examine the effectiveness of vocabulary learning with clay modeling practices during the 2018 Spring and Fall semesters in lower socioeconomic status schools. A series of student tests (pretest, posttest and retention tests), student surveys and teacher interviews were used to collect quantitative and qualitative data. All students were divided into two groups using an online random number generator. Group C students used clay modeling practices to learn and retain assigned biology vocabulary words, while Group S students used sentence writing practices. While Group C students created a clay object for each vocabulary word, Group S wrote three sentences that illustrated the meaning or their understanding of the word. All students participated in either Group C or Group S to learn 20 vocabulary words from the Cells unit first and then switched groups to learn another 20 vocabulary words from the Genetics unit. Allowing student participants to engage in both groups provided data for comparing students' perspectives on both approaches to learning the vocabulary words in each unit.

Data collection began with the administration of a pretest to both groups. Upon completion of the assigned 20 words from the Cells unit by both groups, the posttest was administered. Following the completion of the posttest, the students were given surveys. In the following week, retention tests were given, and teacher interviews were conducted. For the Genetics unit, students switched from the original placement group to engage with the alternate learning method. In other words, Group C students (clay modeling) were placed in Group S (sentence writing), and Group S students were then placed in Group C. This change afforded additional learning experiences for the student participants as well as provided more data on each approach and increased the number of participating students.

Participants

The participants in this study were high school freshmen from two public high schools in a rural, lower socioeconomic status area in the southeastern USA. Five classes taught by two teachers were included in the study: two from the first school in the Spring of 2018 and three classes from the second school in the Fall of 2018. The class sizes varied from 12 to 24 students. From these five classes, 96 students were invited to participate in the study. The schools in the study maintained a block schedule with semester-long courses. The teachers were females with master's degrees and varying years of teaching experience. Before commencing the study, both teachers participated in individual training that included a study overview, examples of clay modeling, vocabulary lists and expectations for the students and themselves. Neither of the teachers had used clay modeling as an instructional resource before this study.

Setting and instruments

The classroom setting had nearly identical room arrangements, with a long counter at the front of the room and a table off to the side where the clay was stored along with all other supplies. Desks were arranged in rows where students sat during class. The students worked at their desks after gathering materials. All students were seated at their desks. All tests and surveys were also administered at the desks. Teacher interviews were conducted one-on-one, either in the classroom or off-campus at a location that was convenient for the teachers.

As shown in Figure 1, the teachers provided Group C students with a clip, a plastic tube and a ballpoint pen for clay modeling practices as vocabulary learning activities. Overall, the students were required to create a clay object to demonstrate their understanding of the definition of an assigned vocabulary word. This was repeated for all 20 words in each unit. All students were allowed to change or improve their clay objects based on their teacher's feedback. Group S wrote sentences (minimum of three) demonstrating their understanding of the meaning of the vocabulary words. For example, a student could write, "The mitochondria provide energy for the rest of the cell." Both groups were free to use textbooks, glossaries or dictionaries.

All 40 vocabulary words were compiled based upon state biology standards and Miller and Joseph's (2002) biology textbook. All of the words used were unique to biology except for "nucleus," which has a different meaning in chemistry and physics. There were two considerations in selecting the list of terms: (1) Is the term necessarily learned in this biology unit? and (2) Is the use of the term likely to be confused with other definitions of the word?

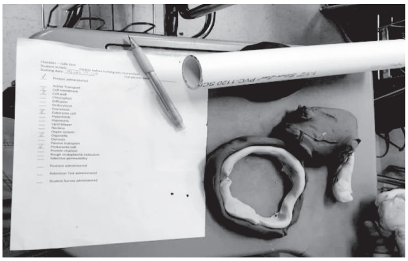
The pretests, posttests and retention tests for each unit were created once the word lists were constructed. All tests were intentionally designed to measure higher-order thinking with challenging questions. Multiple-choice questions are often utilized on standardized tests and were considered appropriate for the assessment. Higher-order thinking skills are critical to overall student success, so the decision was made to include a format that would engage higher-order thinking skills with analogical reasoning (Harrison and Coll, 2008; Richland and Begolli, 2016) within a response format with which students were familiar. Since students were familiar with multiple-choice format questions, the decision was made to use those two options for the assessment.

Each test was composed of 15 analogy questions (multiple-choice response) and five short-answer (open-ended response) questions that allowed students to demonstrate their understanding in their own words (Brookhart and Nitko, 2015). An example of a short answer question used is as follows: "Explain the function of the cell wall." An example of an analogy multiple-choice response question is as follows:

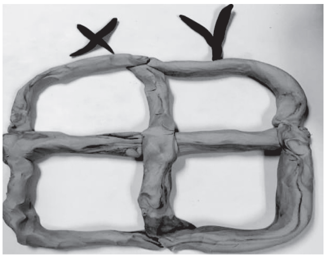
Bricks are to house as macromolecules are to ______

a. Organelles, b. Metaphase, c. DNA, d. Carbohydrates.

The correct answer is "a. Organelles" because macromolecules are used to build organelles in the same manner bricks are used to build houses. Both the tests were given to five educators who were not participants in the study for peer review and critique. They had



Student tools: checklist, clay, rolling pin, & pen



Example of a genetics vocabulary word ("Punnett square") in clay

Figure 1.
An example of clay objects from Group C

degrees ranging from bachelors to doctoral and had taught at the middle school, high school or college level. The feedback from the educators resulted in the rewriting of one question. Overall, the comments were positive and helpful. With the revisions recommended by the peer review addressed, the Institutional Review Boards (IRBs) approved the assessment for use in the study.

The Group C survey consisted of 30 questions ranked on a 1–5 scale (1 = strongly agree and 5 = strongly disagree), while the Group S survey had 25 questions. Each survey consisted of 25 questions that were essentially identical and referred to as mirror questions. For example, a Group C survey question is "The clay helped me understand the words," whereas the Group S mirror question was "The definitions and sentences helped me understand the words." There were five additional questions specific to the use of clay for Group C as shown in Appendix.

The teacher interviews were used to collect teachers' perceptions about the students' learning experiences with clay modeling practices for vocabulary learning in the classroom. Teachers' input as to the effectiveness/ease of use and utilization of clay modeling was also sought. Overall, the interview questions for the teachers progressed from general to specific as shown by these questions: "Tell me about the logistics of working with clay" and "How have you adjusted your lesson preparation to include the use of clay? How did you prepare to work with the clay?" At the end of the interviews, the teachers were asked if there was anything else they wanted to add to the interview or clarify from the interview before closing.

Results

Pretests, posttests and retention tests

Overall, our students' test scores were below expected averages. Even with some passing scores, the means remained at a failing level. The teachers indicated that their students did not have much experience with tests using analogies. Thus, the students had not only new material to master but also a new testing method. The low mean scores are evidence of the rigor of the analogy-based tests for lower socioeconomic status schools.

Table 1 reports descriptive statistics of the test scores. The means in our data indicated that the three test scores showed different patterns between the two units. While the Cells unit score means continuously increased with peaks in retention tests for both Group C (M_{pre} = 27.37; M_{post} = 37.50; M_{ret} = 44.08) and Group S (M_{pre} = 28.42; M_{post} = 43.42; M_{ret} = 46.32), the Genetics unit score means peaked in posttests and decreased slightly after for both Group C (M_{pre} = 29.74; M_{post} = 52.95; M_{ret} = 49.10) and Group S (M_{pre} = 30.77; M_{post} = 51.15; M_{ret} = 41.54). Figure 2 illustrates this contrast between units.

Finding the different patterns (Figure 2), a three-factor ANOVA was performed to examine the effects of group, test timing and unit on test scores. As the test scores collected did not include student identification information, the test scores at three times over two units were treated as independent observations in the inferential analysis. As in Table 2, our data suggest that the overall model significantly explains 23% of the total score variance, $p < 0.01$.

Table 1. Student biology vocabulary test scores by group, test type and unit

Group	Test	Cells unit (N = 38)			Genetics unit (N = 39)		
		M	*SD*	95% CI	*M*	*SD*	95% CI
Group C (Clay)	Pretest	27.37	13.13	[22.63, 32.11]	29.74	15.77	[24.20, 35.29]
	Posttest	37.50	15.06	[32.76, 42.24]	52.95	17.65	[47.40, 58.50]
	Retention	44.08	16.92	[39.34, 48.82]	49.10	18.91	[43.56, 54.65]
Group S (Sentence)	Pretest	28.42	10.97	[23.68, 33.16]	30.77	16.28	[25.22, 36.32]
	Posttest	43.42	15.73	[38.68, 48.16]	51.15	16.40	[45.61, 56.70]
	Retention	46.32	16.30	[41.58, 51.06]	41.54	20.07	[35.99, 47.09]

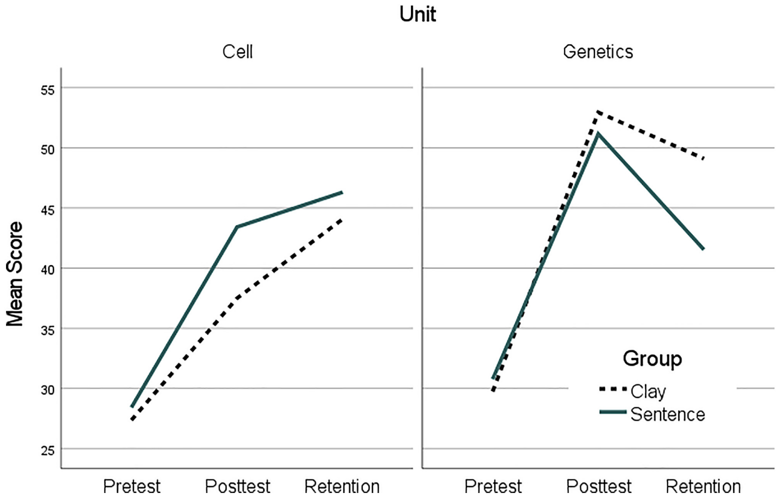


Figure 2.
Comparison of biology vocabulary test scores by group between units

Table 2.
Fixed effects ANOVA results

Predictors	Sum of squares	df	Mean square	*F*	Sig	Partial Eta^2
Corrected model	36104.68[a]	11	3282.24	12.38	<0.01	0.23
Intercept	746365.94	1	746365.94	2815.38	<0.01	0.86
Group	2.47	1	2.47	0.01	0.92	0.00
Time	28642.20	2	14321.10	54.02	<0.01	0.19
Unit	2542.13	1	2542.13	9.59	<0.01	0.02
Group * Time	476.05	2	238.02	0.90	0.41	0.01
Group * Unit	987.32	1	987.32	3.72	0.05	0.01
Time * Unit	2844.58	2	1422.29	5.37	<0.01	0.02
Group * Time * Unit	510.03	2	255.02	0.96	0.38	0.01
Error	119296.46	450	265.10			
Total	903025.00	462				

Note(s): [a]. $R^2 = 0.23$

Table 2 further shows that Group effect was not statistically significant, $p = 0.92$, but Time and Unit effects were $p < 0.01$. A similar pattern was observed with the interaction terms. Only Time * Unit interaction effect was significant, $p < 0.01$. These results indicate that both instructional methods (clay modeling and sentence writing) were similarly effective but the effects differed by learning content.

Interestingly, Unit * Group interaction effect was at the borderline, $p = 0.05$, suggesting that clay modeling or sentence writing may be a more effective method for a certain type of learning content. The remaining interaction effects were not statistically significant. Bonferroni post-hoc tests following the ANOVA indicated that the mean differences between pretests and posttests and between pretests and retention tests were significant, $M_{\text{post-pre}} = 17.24$, $M_{\text{ret-pre}} = 16.17$, $p < 0.001$. Mean differences between posttests and retention tests were not statistically significant.

Given the different descriptive patterns observed (Figure 2) and the borderline significant Group * Unit interaction effect (Table 2), we further examined test score mean differences to explore how clay modeling might have differently affected student's biology vocabulary learning compared to sentence writing. Table 3 reports the test score mean differences by unit and group.

As shown in Table 3, Group C performed at an increase (+10.13) from the pretest (M = 27.37) to posttest (M = 37.50) from the Cells unit results. Unexpectedly, Group S showed more increase (+15.00) from the pretest (M = 28.42) to the posttest (M = 43.42). In addition, Group S showed a higher increase after the retention tests. Group C's scores increased +16.71, while Group S's increased +17.90 from the pretests to the retention tests. One possible explanation may be that the students had more familiarity with sentence-writing practices to learn and retain terminology about cells than genetics.

However, the Genetics unit results were dissimilar in that the Group C students had higher scores than the Group S students on the posttest and retention tests. The scores for the posttest and retention test for Group C increased by +23.21 and + 19.36, respectively. Group S posted an increase of scores, although somewhat lower, for the posttest and retention test with gains of only +20.38 and + 10.77, respectively. Even though the pretest scores in Group C were lower than the scores in Group S, the Group C students outscored the Group S students. Though we initially expected to see statistical differences between the groups on the posttest or the retention test, our results showed no significant differences. The highest positive gain occurred in Group C (+23.21) for the posttest in the Genetics unit. The same students also had the highest net gain after the retention test (+19.36).

Surveys

The students who completed all three tests in Group C and Group S took the survey upon the completion of each unit. The study included participants successfully completing the survey for each unit. The complete data from the surveys for the two groups were analyzed, and the results are presented in Appendix. Overall, the students' view was close to the survey midpoint for many questions on both surveys. For example, the means of Group C (M = 2.81 for the Cells unit and M = 2.90 for the Genetics unit) and Group S (M = 2.87, M = 2.73) appear to neither agree nor disagree. However, there were some different responses between Groups C and S.

To investigate this further, independent t-tests were run on these 25 survey questions. As shown in Table 4, there were significant differences in responses to the Cells and Genetics unit survey questions. For example, the students in Group C from the Cells unit survey were more likely to agree with the following survey questions: "*Q5) Using clay was not necessary for me to understand the words,*" "*Q6) Working with my hands helps me learn,*" "*Q9) I felt that the clay did not improve my understanding of words,*" "*Q16) I wanted to work out more words than were on the list*" and "*Q17) I stayed late or after school to work with the clay,*" while the students in Group S were more likely to agree with two other survey questions: "*Q19) I remembered words better after I used sentence writing,*" and "*Q21) The sentence writing was boring after a while*".

Among these, it worth noting that relatively large between-group mean differences was found in *Q16* ($M_{C\text{-}S} = -1.18$) and *Q19* ($M_{C\text{-}S} = 1.58$). These results indicate that students who used clay modeling to learn Cells vocabulary were more likely to want to work out more words but less likely to perceive that they remembered words better after using the method. The student responses were similar after using clay modeling for Genetics vocabulary learning for *Q19* ($M_{C\text{-}S}$ = 1.46), suggesting that students overall disagreed that they remembered better after clay modeling.

Table 3.
Test score mean differences by unit and group

Unit	Group	$M_{Post\text{-}Pre}$	$M_{Ret\text{-}Pre}$	$M_{Ret\text{-}Post}$
Cells	Clay	10.13	16.71	6.58
	Sentence	15.00	17.90	2.90
Genetics	Clay	23.21	19.36	−3.85
	Sentence	20.39	10.77	−9.62

Unit	Question	Group	N	M (SD)	df	t	p	Cohen's d
Cells unit	Q5	Group C	38	2.55 (1.03)	74	−2.499	0.015	−0.58
		Group S	38	3.16 (1.08)				
	Q6	Group C	38	2.42 (1.15)	74	−2.785	0.007	−0.65
		Group S	38	3.11 (0.98)				
	Q9	Group C	38	2.79 (1.04)	74	−2.395	0.019	−0.55
		Group S	38	3.34 (0.97)				
	Q16	Group C	38	2.45 (1.06)	74	−4.957	0.000	−1.13
		Group S	38	3.63 (1.03)				
	Q17	Group C	38	2.79 (1.02)	74	−3.307	0.001	−0.75
		Group S	38	3.63 (1.20)				
	Q19	Group C	38	4.21 (0.94)	74	6.572	0.000	1.50
		Group S	38	2.63 (1.15)				
	Q21	Group C	38	2.87 (1.07)	74	3.287	0.002	0.76
		Group S	38	2.08 (1.02)				
Genetics unit	Q10	Group C	39	3.03 (1.09)	76	3.449	0.001	0.79
		Group S	39	2.28 (0.79)				
	Q17	Group C	39	2.85 (0.93)	76	−3.554	0.001	−0.80
		Group S	39	3.74 (1.27)				
	Q19	Group C	39	4.00 (1.03)	76	6.740	0.000	1.52
		Group S	39	2.54 (0.88)				
	Q21	Group C	39	2.90 (1.25)	76	3.172	0.002	0.72
		Group S	39	2.05 (1.10)				
	Q25	Group C	39	3.05 (0.92)	76	2.188	0.032	0.50
		Group S	39	2.56 (1.05)				

Note(s): 1 = strongly agree, 2 = agree, 3 = neither agree nor disagree, 4 = disagree and 5 = strongly disagree

Table 4. Survey questions with statistically significant *t*-test results ($p < 0.05$)

The students in Group C also responded to the additional questions shown in Table 5. The items are designed to address potential negative aspects of learning through clay modeling. Our data suggest that while students varied thoughts about potential negative aspects of working with clay with standard deviations ranging from 0.81 to 1.22, they generally agreed that they played with the clay more than they needed to (*Q27*).

Teacher interviews

Each teacher participated in an interview after the completion of each unit for a total of four interviews. The teachers responded succinctly but gave enough information to determine various themes in their answers. Upon completion of the interviews, the responses were analyzed, and four themes were identified as shown in Table 6.

The interview responses displayed in Table 6 include positive and negative themes, consistent with what was observed in the student survey data. The positive comments

Question	Statement	Cells unit M	Cells unit SD	Genetics unit M	Genetics unit SD
Q26	I could not shape the clay into what I wanted	2.42	1.08	2.87	1.22
Q27	I played with the clay more than I needed to	2.18	0.90	2.32	0.89
Q28	The clay was messy	2.79	1.04	3.10	0.81
Q29	I did not like cleaning up the clay area	3.39	1.03	3.60	0.98
Q30	I had to work with the clay for a while until an idea came to mind	3.29	1.14	3.38	1.13

Note(s): 1 = strongly agree, 2 = agree, 3 = neither agree nor disagree, 4 = disagree and 5 = strongly disagree

Table 5. Additional group C students' responses

Themes	Example responses
Excitement	"Different method was exciting" "At first they were very excited to play with the clay" "Novelty was interesting for them" "They were excited to play with the clay" "Very excited the first time" "Enjoyed it"
Engagement	"More engaging" "Actively engaged" "Some were really into clay" "They were more involved" "Engaged more with the clay"
Hands-on	"Appreciate hands-on" "They like the hands-on" "Loved the hands-on" "Boys more into hands-on"
Clay hardness/Difficulty	"Initially hard to work with. Breaking up was hard" "Hard clay but overall, they enjoyed it" "The clay was a little hard" "Little hard, expecting play dough" "Happy with the clay but it was hard"
Too much work	"Complaining about how much work clay was" "Got tired. Took longer than sentences" "Maybe 20 words was too much" "Five words at a time, break it up"

Table 6.
Themes by question from teacher interviews

related to the students' excitement and engagement when working with the clay. The teachers stated that the students were excited to use the clay and engaged when creating clay objects. Most of the negative comments dealt with the difficulty in manipulating the clay. The second negative aspect concerned the amount of work it took to use the clay.

Discussion

How does clay modeling in high school biology classes affect student vocabulary learning? Group S students had more positive responses to both Cells and Genetics unit survey question *19, "I remembered words better after I used sentence writing*." Regardless to say, the clay modeling activity was not designed to recall each word's spelling or pronunciation simply. This new hands-on activity required students to understand each word's meaning and then express their thoughts and ideas to produce physical and visual clay objects of biology terms. Although our test results showed no statistically significant differences between the groups, adding the clay modeling improved students' vocabulary acquisition just as much as the sentence writing practices, as shown in Figure 3. As a teacher explained, "*The study clay*

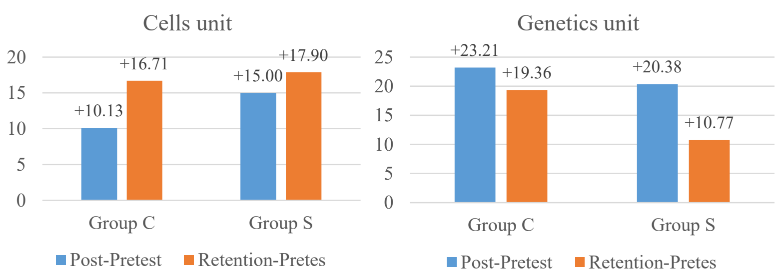


Figure 3.
Graphic representation of the gain scores

group made them think about how they would represent the definition, extra thinking may have helped." In other words, adding kinesthetic practices with clay to illustrate their understanding of the words to be defined produced similar results as the traditional sentence writing to learn and retain the words.

Furthermore, the Genetics test results show that Group C had better gain scores (+23.21 and +19.36) than Group S (+20.38 and +10.77). Vocabulary acquisition can be influenced by student preferences and prior knowledge. However, adding clay modeling assisted students in perceiving and comprehending their vocabulary learning. Group C students responded more positively to the Genetics unit survey question *"Q17) I stayed late or after school to work with the clay*." In contrast, Group S students responded positively to "*Q21) The sentence writing was boring after a while*." This interesting finding could explain why Group C had higher scores in the Genetics unit than Group S. In this case, students wanted to use the clay to learn and retain the words in the classroom. Adding a kinesthetic experience with clay could be another way to teach vocabulary to students once they have positive experiences. In the interviews, the teachers indicated that the students were excited and engaged with hands-on activities that demonstrate positive learning experiences with the clay. The most common phrases used to describe the benefits were "excited," "engaged" and "hands-on." Although more studies are needed, adding kinesthetic practices with clay can increase emotional (e.g. excitement), behavioral (e.g. engagement) and physical (e.g. hands-on) benefits that lead to positive learning experiences.

What are participants' suggestions to improve learning experiences with the clay modeling?
The first challenge was the difficulty in manipulating the clay itself. Many students experienced difficulty using rulers and rollers to create clay objects. The teachers mentioned that the physical difficulties included "*Scissors to cut clay*," "*Can't work with knives, but maybe plastic knives*" and "*Happy with the clay, but it was hard*." These physical challenges forced teachers to allow more class time for the activity to prevent students from giving up on creating clay objects. This unintended challenge led to another emotional and behavioral challenge as the teachers responded, "*Complaining about how much work clay was*" and "*Got tired. Took longer than sentences*." As shown in Table 5, some students could not shape the clay into what they wanted and were forced to work longer than expected.

Our test data analyses indicate that the two instructional practices are similarly effective, but students tended to think that the sentence writing practices were more effective rather than the clay modeling practices, as seen in the responses to the Genetics survey questions (See Table 4): "*Q10) Using sentence writing helped me mentally picture things more clearly*," $t(77) = 3.491$, $p = 0.001$, "*Q19) I remembered words better after I used sentence writing*", $t(77) = 6.663$, $p < 0.001$, and "*Q25) Using sentence writing helped me with pronunciation of the vocabulary words*," $t(77) = 2.210$, $p = 0.030$.

The teachers provided input on the challenges and concerns of using the clay modeling practices. Practical pedagogical comments, such as *"Maybe 20 words was too much"* and *"Five words at a time, break it up,"* reflected their perceptions and recommendations for improving the implementation of clay modeling as an instructional resource. The clay modeling practices unquestionably took more time than writing sentences to learn vocabulary. Their suggestions imply that we should apply appropriate instructional strategies to design and implement effective clay modeling practices for students and teachers. For example, simplifying tools and materials will minimize emotional and behavioral challenges associated with clay modeling practices. In addition, adding kinesthetic learning practices will not always be effective for all students. Providing a new channel with action (e.g. clay modeling) for vocabulary learning may lead to unnecessary cognitive load in the learning process. To promote positive learning experiences, teachers should create a physically and pedagogically appropriate learning environment for all students (Kim *et al.*, 2017). Training or professional development for classroom teachers will be another consideration. Teachers need to better understand students' practical and pedagogical needs when exploring the benefits of clay modeling practices. Teachers and students were both challenged by the process of creating clay objects as it took more steps and longer time to complete. Some students indicated they stayed longer in class or came back later in the day to complete the assignment. This added an additional instructional load for teachers and time commitment for students.

Last, we should note that without technical support assistance, the benefits of learning with clay will not be apparent. The actual practicality and difficulty of using the clay frustrated students who had initially felt happy with the clay as a teacher commented, "*Happy with the clay but it was hard*." When students have challenges inside or outside the classroom, teachers must be aware of these challenges and accommodate them to support student learning. Additional preparation for the teachers would assist in alleviating some of the challenges incurred in the implementation of the clay modeling practices.

Conclusion

The students participating in this study appeared to benefit from the clay modeling practices as they learned and retained biology vocabulary. The students were able to create clay objects to understand components of cells and concepts in genetics they might never have attempted or conceived before. Aside from being enthusiastic and absorbed with hands-on activities using the clay, the students demonstrated positive emotional, behavioral and physical experiences. One teacher noted that "boys (appear to be) more into hands-on" suggesting the need to examine further gender differences in future studies with kinesthetic learning practices.

Our data showed that although students perceived clay modeling to be an ineffective learning method, their vocabulary scores improved as much as those who learned through sentence writing. A potential explanation for such negative perceptions about clay modeling is that it was unconventional, and making clay models of challenging biology vocabulary could have created a high extraneous cognitive load for students despite the benefits of kinesthetic learning. This challenge can be reduced by 1) adopting appropriate instructional strategies to design and implement effective clay modeling activities for students and teachers, 2) providing training or professional workshop development for teachers to better support students during kinesthetic learning practices and 3) providing ongoing practical support and assistance for students.

In order to understand how the clay modeling activity works as an instructional/learning strategy, students must be prepared before initiating the clay modeling activity and contribute to the success of the project. A more pliable type of modeling clay should be considered. The hardness of the clay used in this study appeared to be a frustrating issue for students and teachers alike. Teachers, likewise, would need professional development to understand the benefits of kinesthetic learning resources, such as clay modeling, for nontraditional content areas, such as biology.

Exploring the use of kinesthetic instructional practice at the high school level may prove beneficial since clay modeling is frequently used effectively at lower grade levels. Utilizing technical resources to assist with learning how to use the clay or to support students off-campus might have lessened the need to stay after class or school. Having such a resource in place would benefit both students and teachers. With the many instructional resources available to encourage, excite and enrich students' learning, it is rewarding to see teachers willing to participate in a challenging study that produced good results academically for the students, even if the results of the study were not found to be significant.

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Appendix

Item	Cells unit Group C (*N* = 38) *M*	*SD*	Cells unit Group S (*N* = 38) *M*	*SD*	Genetics unit Group C (*N* = 39) *M*	*SD*	Genetics unit Group S (*N* = 39) *M*	*SD*
1) The clay helped me understand the words	2.68	1.14	2.26	0.80	2.69	1.03	2.26	0.99
2) I learned to appreciate the clay as I did more words	2.50	1.11	2.71	1.01	2.74	1.07	2.38	0.99
3) I came to dislike using the clay as time went on	2.82	1.21	2.87	1.10	2.85	1.20	2.90	0.97
4) I could picture the meaning of words better with clay	2.55	1.08	2.82	1.14	2.79	1.06	2.59	0.94
5) Using clay was not necessary for me to understand the words	2.55	1.03	3.16	1.08	2.67	1.08	2.87	1.20
6) Working with my hands helps me learn	2.42	1.15	3.11	0.98	2.67	1.08	2.90	1.12
7) After making a few clay creations I felt I did not need to make anymore	2.92	1.10	2.97	0.97	3.03	1.11	2.77	1.06
8) It was hard to work with the clay	2.97	1.37	3.03	1.26	3.26	1.09	2.77	1.18
9) I felt that the clay did not improve my understanding of words	2.79	1.04	3.34	0.97	3.38	0.99	3.23	1.14
10) Using clay helped me mentally picture things more clearly	2.89	1.25	2.63	0.88	3.03	1.09	2.28	0.79
11) I created more clays to learn the vocabulary words than I needed	2.53	1.01	2.79	1.23	2.54	1.07	3.00	1.28
12) I think clay should be used in other classes too	2.87	1.14	2.71	1.09	2.82	1.05	2.59	0.94
13) The clay helped with definitions more than simply using a dictionary or glossary	2.50	1.06	2.55	0.95	2.31	1.13	2.49	1.02
14) Using the clay took too much time	2.89	1.18	2.45	1.18	2.74	1.21	2.67	1.24
15) Creating definitions of words in clay became faster and easier as I did more words	2.97	0.89	2.82	0.98	2.97	1.01	2.62	1.14
16) I wanted to work out more words than were on the list in clay	2.45	1.06	3.63	1.03	2.79	1.08	3.28	1.21
17) I stayed late or after school to work with the clay	2.79	1.02	3.63	1.20	2.85	0.93	3.74	1.27
18) I found myself looking forward to using the clay	3.26	1.11	3.39	1.08	3.31	1.13	3.00	1.40
19) I remembered words better after I used clay	4.21	0.94	2.63	1.15	4.00	1.03	2.54	0.88
20) I feel like I could turn any word into a clay creation	2.50	1.03	2.82	1.09	2.77	1.04	2.82	1.07
21) The clay was boring after a while	2.87	1.07	2.08	1.02	2.90	1.25	2.05	1.10
22) Every word presented a new challenge	2.84	1.08	2.55	0.65	2.69	1.08	2.49	0.97
23) I already knew what to do and the clay did not help clarify anything	3.18	1.06	3.18	0.90	2.85	0.96	3.03	1.33
24) Using the clay helped me with spelling	2.68	1.09	2.79	0.96	2.59	0.99	2.49	0.97
25) Using the clay helped me with pronunciation of the vocabulary words	2.63	1.13	2.74	1.13	3.05	0.92	2.56	1.05
Total	2.81	1.09	2.87	1.03	2.89	1.07	2.73	1.09

Note(s): 1 = strongly agree, 2 = agree, 3 = neither agree nor disagree, 4 = disagree and 5 = strongly disagree

Table A1. Survey results for group C and S

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