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Effectiveness of Problem-Centered Learning in Enhancing Senior High School Students' Achievements in Genetics

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ABSTRACT

The 21st-century skills seek to develop learners who will be problem solvers in society. This paradigm shift requires the use of learner-centered strategies that emphasize collaborative problem-solving. To explore the effectiveness of such approaches, this study sought to determine how effective Wheatley's problem-centered approach would be in the attainment of learning outcomes of students in genetics by comparing it to the conventional teaching approach. Using an embedded mixed-methods design, an intact class was selected randomly from two schools. The pre-test-post-test non-equivalent group design was used to obtain quantitative data, while interviews were used to obtain qualitative data. The students in the experimental group learned biology concepts using the Wheatley model while those in the control group were taught the same concepts through the conventional teaching approach. Students in the experimental group performed better on the post-test than those in the control group. The performance of the low achievers within the experimental group also improved. Students expressed an overall positive attitude toward the use of the Wheatley model as an instructional strategy. It was therefore recommended that biology teachers should employ the Wheatley model in the teaching and learning of biology at the Senior High School level.

Keywords: problem-centered learning; Wheatley model; high school biology; instructional approach; constructivism

Introduction

Stakeholders in education over the years have placed responsibility on teachers for students' academic failures. Such blame emanates from the fact that teachers are seen as an integral component of the schooling process. Teachers' personalities, knowledge, attitudes, and pedagogical strategies affect the attainment of learning outcomes for students. For successful and effective teaching, teachers are required to select appropriate pedagogical strategies that can maximize students' learning. Abell et al. (2010) argued that teachers' pedagogical actions affect students' learning outcomes. Therefore, poor teaching approaches are claimed to be one of the major pivotal issues to students' poor performance in the sciences (Abell et al., 2010; Hassard & Dias, 2013).

Consequently, teachers must explore and use appropriate approaches to teaching to facilitate and maximize students' learning. However, the task of selecting an appropriate pedagogical strategy becomes daunting with the availability of several teaching methods. Although there are several teaching approaches, educationists believe that for effective teaching, teachers must employ constructivist teaching strategies (Fosnot, 1989; Steffe & Gale, 1995; Tobin & Tippins, 2012; Zemelman et al., 1993).

The call for the utilization of constructivist teaching approaches is hinged on the assumption that such approaches are student-centered, foster student collaboration, and increase students' academic achievement. The learners are assumed to create their knowledge and meaning through interaction with others (Hand et al., 1997). Learners, through their personal experiences, socially interact with others to arrive at an appropriate understanding of content (Bruning et al., 2004). Individual learners ultimately construct a personal version of the socially negotiated meaning (Taber, 2012). Learners' conceptualizations of scientific concepts are enhanced as they interact, discuss, and elaborate ideas with their colleagues (Mazur, 1997).

Aulls (2002) refers to such discussion as academic discourse and notes that substantive academic discourse facilitates students' exploration of curriculum topics and material. Students' ability to argue and communicate is enhanced through discussions they engage in during cooperative and group learning (Pagan, 2016). Such discussion involves students talking about the subject and arriving at their conclusions rather than simple, routine interactions between instructors and students (Aulls, 2002). Students' learning, therefore, is not based on the instructor's instruction but rather on the students' work (Schuh, 2003).

Constructivist approaches provide students with skills that can be used outside the classroom as well as reinforce social cognition (Aulls, 2002). These traits are developed because constructivist instructional goals facilitate student application of external knowledge sources and encourage students to utilize scientific reasoning as they solve realistic, real-life problems collaboratively, leading to the development of elicited social cognition (Echevarria, 2003; Petraglia, 1998). Thus, effective constructivist instruction leads to the development of various skills needed for a successful existence in the 21st century.

The developers of the Ghanaian Senior High School (SHS) Biology syllabus realize the strengths of student-centered approaches and have therefore advocated for its use in the teaching and learning of Biology concepts at the SHS level (Curriculum Research and Development Division [CRDD], 2010). Moreover, the new Ghanaian curriculum for the pre-tertiary level also emphasizes that science education should produce learners who will be problem solvers and innovators through the contextualisation of learning, making students act as knowledge creators (National Council for Curriculum and Assessment [NaCCA], 2020). The idea is to enable learners to become knowledge creators, drawing from their prior experiences. This shift in teaching philosophy calls for constructivist paradigms and approaches.

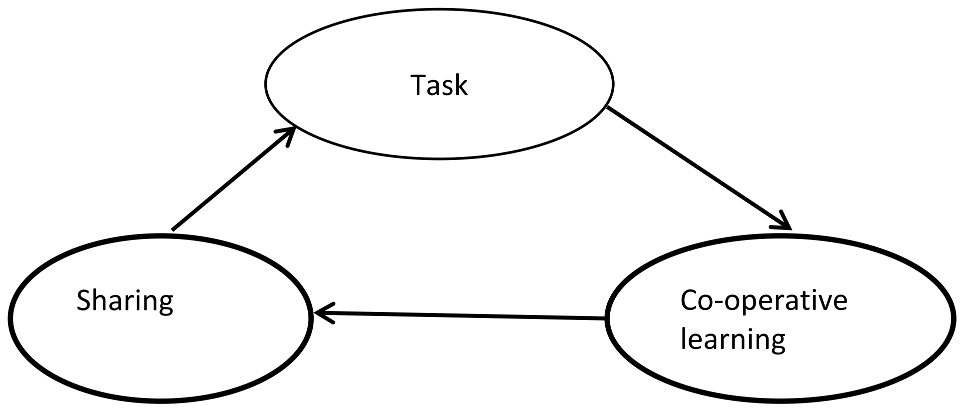
Unfortunately, the call for a shift to constructivist approaches is not supported by the suggestion of specific strategies to be used even though Ghana operates a syllabus system where teaching activities are explicitly suggested. This creates a situation where Ghanaian biology teachers find themselves in a conundrum as to which of the approaches will be best suited for the peculiarities of their students' learning and their classroom environments. Thus, to successfully entice teachers to use constructivist approaches, efforts should be made to identify strategies that will be appropriate for the Ghanaian context.

One of the constructivist approaches that is effective and efficiently employs real-life contextualized problems is the Wheatley model (Wheatley, 1989). Wheatley pointed out that knowledge is not passively received but actively built up by the student in the learning process through the solution of realistic problems in a social setting. In this approach, a student's ability to organize information in unique ways and relate with others to have shared knowledge in a community constitutes learning. To facilitate the development of personalized learning, teachers are expected to guide learners through the provision of motivating and challenging tasks that learners will accomplish through social dialogue (Wheatley, 1991).

The Wheatley model is a problem-centered teaching model that is made up of three components: task, cooperative learning, and sharing. The Wheatley model is shown in Figure 1.

Figure 1

Wheatley Model Adapted (Wheatley, 1989).



The model begins with a task to be performed by students. The task is a concept or a topic that may cause a problem for students in their learning process. The task should consist of a set of problematic issues that address the core concepts of the subject. Such tasks facilitate the development of in-depth cognitive models (Dolmans & Schmidt, 2000), leading to the development of effective problem-solving skills, flexible knowledge, and self-directed learning skills (Hmelo-Silver, 2004). The provision of tasks to students provides an avenue for them to draw on their experiences to come up with uniquely personal solutions. Wheatley (1991) accentuated that "the core of problem-centered learning is a set of problematic tasks that focus attention on the key concepts of the discipline that will guide students to construct effective ways of thinking about that subject" (p.16). An appropriate and effective task should incorporate interdependence among students without compromising individual student accountability (Jolliffe, 2007). To successfully achieve the benefits of problem-centered learning, Wheatley (1991) argued that the task should motivate students to dialogue and communicate, make informed decisions, ask higher-order questions, be enjoyable, and encourage the transfer of learning.

Students work on the task in cooperative groups. Slavin (2011) explained cooperative group/learning as “an instructional method in which instructors organize students into small groups, which then work together to help one another learn academic material” (p. 344). Cooperative learning helps students to meet colleagues who have marginally advanced cognitive levels, one within the student's zone of proximal development (Applefield et al., 2000). The improvement of learning outcomes collectively by the group of learners is underpinned by the principles of positive interdependence where the attainment of individual outcomes is hinged on the success of other group members and individual accountability where every student contributes effectively to the group work (Abramczyk & Jurkowski, 2020; Johnson & Johnson, 1985; Jolliffe, 2007; Slavin, 1995).

The creation of positive interdependence and the contribution of individual efforts through individual accountability creates a social constructivist classroom (Applefield et al., 2000). Teachers believe that such interactions in cooperative learning foster the development of personal and social learning (Abramczyk & Jurkowski, 2020). Therefore, to achieve the utmost benefit of cooperative learning, students should not just be put in groups with the hope that they will work effectively

(Jolliffe, 2007; Veldman et al., 2020), but rather conscious efforts should be made to ensure that the task demands interdependence and accountability on individual students (Jolliffe, 2007).

Finally, the sharing stage seeks to give time to students to present their solutions, inventions, and insights (Wheatley, 1989). Students in various groups share their ideas with the class, whereby they learn to socially negotiate to come to an acceptable compromise when they disagree on answers and methods (Wheatley, 1991). Students' level of mastery and conceptualization of concepts improve when they can successfully explain concepts, methods, and answers to their contemporaries (Brooks & Brooks, 1999).

Moreover, students develop communication skills and master creative thinking as a result of effectively sharing their views with their peers. Here, the group shares their outcome or solution to the problem, and those listening develop the skill of honest talk and active listening respectively (Jolliffe, 2007). Ultimately, the sharing stage will facilitate the development of students' language skills and bring to the fore contentious issues and different perspectives on the solution to the task undertaken. (Kagan & Kagan, 2009). Students have lots of ideas to share, and when they master the completion of tasks in a group, the internalization of information arises for each person to diverse degrees, according to their personal experience.

Although the problem-centered approach is a student-centered learning strategy, teachers have their roles to play. The teacher observes and interacts with the students as they search for their information in their cooperative groups and provides support to the whole group instead of individual students (Wheatley, 1991). Teachers should serve as role models in terms of behavior expected to be seen in students during the enactment of problem-centered approaches (Veldman et al., 2020). Such behavior modeling should be seen throughout the learning period through the demonstration of facilitating skills and an impartial, non-judgmental role during the sharing period (Wheatley, 1991).

Since the Wheatley model is found to maximize students' learning in a collaborative environment, it will be prudent if its effectiveness is ascertained in the teaching and learning of genetics concepts in the Ghanaian educational context. In this regard, this paper reports the outcome of research conducted to explore the effectiveness of the Wheatley model in the teaching and learning of genetics concepts. The following hypotheses and research questions guided the research:

Ho_1: There is no statistically significant difference between the achievement scores of students exposed to the Wheatley model and students exposed to conventional instruction.
H_{02}: There is no statistically significant difference between the post-test scores of low achievers and high achievers when instructed through the Wheatley model.

Research question:

What are students' attitudes toward the Wheatley model as an instructional strategy?

Methods

Research Design and Procedure

The research design that was employed for this study was the quasi-experimental control and experimental non-equivalent group design since the subjects were not assigned randomly to the control and the experimental groups (Shadish et al., 2002; White & Sabarwal, 2014). The design was appropriate because it reduced the interactive effect of treatment and increased the external validity of the findings (Creswell & Plano Clark, 2011). In addition, the choice of quasi-experimental design for the study allows the investigation of intact groups in real-life classroom settings since it was not necessary to randomly assemble students for any intervention during the school hour to create artificial conditions.

Two senior high schools were randomly selected from the senior high schools that offer elective science subjects through the use of a table of random numbers. The school that was selected first was the experimental group, and the second school selected was the control group. In this study, the performance of students was the dependent variable, whereas the teaching strategies (the Wheatley model and a conventional approach) were the independent variables. The study used two separate treatments. The control group was taught through the conventional approach of teaching. In this approach, the teacher-led class interaction mostly explained concepts to students. The approach in this group was a typical lecture technique of teaching interspersed with questions to which students had to respond. The experimental group was taught the same topic using the Wheatley model. Both groups were taught simultaneously.

To ensure that there was no interaction effect, the selected schools were in different towns but within the same municipality. Since the teacher factor is an important variable of instruction, the same teacher taught both groups. It was ensured that the content to be delivered was the same, with the only differing attribute being the pedagogical approach through which the concepts were delivered. A post-test was conducted to ascertain the performance of both groups after the instruction. All the students in the experimental group were interviewed. Interviewees were given assurance of confidentiality and anonymity before the interview session. Express permission was also sought from the headmasters of the schools in which the study was conducted. The third layer of permission and consent was sought from the students in both groups. Students were assured of the confidentiality and anonymity of their responses, especially those who were interviewed. The interviewees were made aware that their responses would be recorded with an audio tape recorder.

Sample

Seventy-five senior high school year two students drawn from two intact classes from two randomly selected schools in the Bolgatanga Municipality of the Upper East Region of Ghana constituted the sample for the study. There were 41 students in the control group and 34 students in the experimental group. In each school, the simple random sampling technique was used to select one intact class for the study. The two selected classes from the two schools were categorized as experimental and control groups based on a pretest conducted after the classes were selected.

Instrument

Biology achievement tests (pre-test and post-test) and interview schedules were employed as the instruments for this study. The pre-test was based on first-year topics in the biology syllabus, which the students in both groups had been taught. The pre-test was used to ascertain whether the two groups were performing at the same level before the experiment and therefore comparable in terms of achievement. Thus, the pre-test was used to identify the entry characteristics of the students to determine if they shared similar traits and attributes. Again, since the focus of the paper was on students' performance on the post-test, it was deemed not appropriate to assess the students on the yet-to-be-treated concepts since the use of the same test items for pre-test and post-test could confound students' actual performance.

The pre-test was also used to group the students in the experimental group into low achievers and high achievers. Students with scores lower than the group mean on the pre-test were categorized as low achievers, and those with scores above the mean were termed as high achievers. Post-test was based on the topic of genetics, which was taught during the intervention to find out students' performance after the intervention. There were 25-item multiple-choice questions in the pre-test and the post-test. The pre-test and post-test items were used to find out the performance of the students before and after the intervention, respectively. The Kuder-Richardson (KR) 20 coefficient of reliability test was established for the achievement test items. The result indicated a reliability coefficient value of 0.7, indicating reliable test items for a classroom test. The KR 20 was used because the test items were multiple-choice questions and were scored either correct or incorrect. A semi-structured interview, which forms part of the instrument for the study, was used to find out how the students found the Wheatley model in terms of interest, understanding of the course content, and difficulties they might have encountered while working with the teaching model.

Data Analysis

Quantitative and qualitative analyses were used in this study. The independent sample *t*-test was used to analyze the quantitative data from the pre-test and post-test. The independent sample *t*-test was used to find out if there existed any statistically significant difference between the post-test scores obtained by students exposed to the Wheatley model as compared to the scores obtained by students exposed to conventional instruction. The independent sample *t*-test was again used to find out if there were any statistically significant differences between high achievers and low achievers on the post-test scores when they were taught using the Wheatley model. The responses from the interviewees during the interview session were themed, transcribed, and analyzed to unearth the attitude of the students toward the Wheatley model.

Results

The first null hypothesis sought to indicate that no significant difference would be found between the means of the post-test scores obtained by students exposed to the Wheatley model as compared to the scores obtained by students exposed to conventional instruction. To test this hypothesis, the independent sample *t*-test showed that the pre-test scores of the experimental group and the control group were not statistically significant (t = 1.0441, df = 73, p =.299) as can be seen in Table 1.

Table 1

Independent Sample t-test Analysis of the Scores of the Experimental and Control Groups on the Pre-test and the Post-test

	Group	***N***	**Mean**	**SD**	***df***	***t*-value**	***p*-value**
Group scores on the pretest	Experimental	34	12.26	2.400	73	1.0441	.299
	Control	41	12.90	2.827			
Group scores on the post-test	Experimental	34	15.97	1.714	73	4.694	.000
	Control	41	13.17	3.106			

Significance *p<0.05

This indicates that there was no difference in performance between the two groups before the study was conducted. The *t*-test results, however, showed a statistically significant difference between the two groups (t = 4.694, df = 73, p < .001) in post-test scores of the achievement test. This information is displayed in Table 2. The null hypothesis is therefore rejected, indicating that the Wheatley model (experimental) group performed better with a Mean of 15.97 and SD of 1.714 than those taught by the conventional approach (control) group with a Mean of 13.17 and SD 3.106. The outcome indicates a large boost for the use of the Wheatley model in science classrooms.

The second hypothesis, that there is no statistically significant difference between the post-test scores of low achievers and high achievers when instructed through the Wheatley model, was tested with the independent sample *t*-test and the results are presented in Table 2.

Table 2

Results of the Independent Sample t-test Analysis on the Pretest Scores of High Achievers and Low Achievers in the Experimental Group

Students score on	**Achievement level**	***N***	**Mean**	**SD**	***t***	***df***	***p*-value**
Pretest	High achievers	23	12.26	1.287	-6.853	32	.000
	Low achievers	11	9.18	1.079			
Posttest	High achievers	23	16.35	1.774	-2.308	32	.028
	Low achievers	11	15.00	1.095			

Significance *p<0.05

At the onset of the research, there was a significant difference between students categorized as high achievers and those categorized as low achievers in favor of the high achievers, as can be seen in Table 2. There is an indication that high achievers were performing better than low achievers before the study was carried out, with a higher mean score. On the post-test, the results from the independent sample *t*-test were still statistically significant (t = -2. 308, p = .028) on the post-test as can be seen in Table 2. This implies that when students are taught using the Wheatley model, high achievers will continue to perform better than low achievers. The null hypothesis of no significant difference between the performance of high achievers and low achievers, when taught using the Wheatley model, is therefore rejected.

The research question sought to identify students' attitudes toward the teaching and learning strategy. Students' voices are very important in the introduction of any new strategy. Thus, the students who were instructed with the Wheatley model were interviewed to gauge their attitude toward the instructional approach. Since attitudes are a multidimensional construct with different sub-constructs (Kind et al., 2007; Osborne et al., 2003), students' responses to the interviews were grouped into themes reflecting different aspects of their attitudes towards the teaching strategy. The themes that emerged from the interviews were excitement about the learning process, understanding of concepts, collaboration in the teaching process, and instructional time.

Osborne et al. (2003) identified the 'enjoyment of the learning process' as an aspect of students' attitudes toward science. Learners draw on their prior experiences to learn new concepts therefore, if the learning situation is not exciting to them, the likelihood of engaging in further learning is minimized. The teaching and learning process should be enjoyable to the student, especially when a new teaching approach is being introduced. The majority of the students who were instructed with the Wheatley approach found it to be interesting and exciting. The students found the opportunity to explore and contribute to the learning process very exciting. Students' views were typified by comments such as those presented as follows:

> Student 1" I was very excited because the approach has helped some of us to contribute well in class and that was interesting".
> Student 4 noted that the approach was very good "because you can contribute and share ideas in class".
> Student 7 "I was very happy because I had to search for information before presentation which was exciting because we don't do that in class".

Teachers teach with the hope that their students will understand science concepts, which will lead to increased and improved achievement in the scores of students. 'Achievement in science' has therefore been identified as an aspect of the overall attitudes of students toward science (Osborne et al., 2003). The difference in the mean scores of the students in the Wheatley instructional group and students in the control group was statistically significant; nonetheless, it was necessary to gauge students' views on their conceptual understanding when instructed with the Wheatley model. Students expressed how the approach enabled them to understand the concepts taught. "I understood the concepts very well," Student 2. She continued that "learning with peers is much (sic) interesting and helps in understanding than with the teacher". Student 3 sought to explain the reason why he understood the concepts by indicating that "we interacted and argued to come out with correct explanations".

A cardinal attribute of any constructivist approach is social interactions among students (Liang & Gabel, 2005). Since the Wheatley model is constructivist, the social interaction component needs to be realized. Students were asked to indicate their views on the interactions they had during the teaching and learning process. Students indicated that they were able to share ideas with their peers as they were exposed to the Wheatley model. Student 3 voiced that he was able to share ideas, "especially where terms were not clear to the group and wouldn't have understood everything alone". Student 6 stated that "I shared ideas with colleagues, some words are different in spelling but the same in meaning" and that she wouldn't have wished to learn genetics alone "because I would have had information in one direction". Student 10 stated that "group learning is better than sitting in class to learn with a teacher".

The final aspect of student attitudes toward the approach used in this study was instructional time. It was prudent that students' views towards the duration of the learning process were gauged to alert teachers. Some of the students indicated that the time allocated to them to search for information related to the concepts and report back to the class was not enough. Student 1 said, "I wish we had more time." Student 4 noted that "time was not enough". Student 5, on his part, answered that the "time was not that adequate". Instructional time is a critical aspect of the variables that influence the outcome of the teaching and learning process. When students and teachers do not have enough time to facilitate the teaching and learning process, the most salient concepts are ignored or rushed through. The consequence of not either completing the content material or covering it superficially is that students' conceptual understanding is likely to be impaired.

Discussion

The outcome of the study indicates that students taught through the Wheatley model performed better than those taught through the conventional approach. This result is similar to that obtained by Wheatley (1989), who found the approach superior to the conventional teaching strategy in terms of students' academic achievement. Wheatley (1991) argued that students' higher academic achievement could be because when teachers set activities for students, it forces the restructuring of ideas at a higher level than using the explain-practice paradigm. Kim (2005) found that the use of a constructivist approach improved students' achievement when compared to the conventional teaching strategy. The various forms of the constructivist approaches have been found to generally have superior ability than the conventional approach in improving students' conceptual understanding and overall learning outcomes (Liang & Gabel, 2005).

Students' responses during the interview session indicate a very high level of satisfaction and positive attitude towards the use of the Wheatley model. There was increased student participation, which brought out diverse views on the learning process. Wheatley (1989) noted that "knowledge is not passively received but is actively built up by the cognizing subject and to know is to understand in a manner which can be shared by others (p. 164)". The increased student participation and excitement can be attributed to the fact that students could challenge the views of their colleagues through collaborative efforts. This provided a conducive environment for them to learn, which was in line with suggestions made by Wheatley et al. (1995), indicating that students learn best when they are provided with the appropriate challenging problem in a collaborative environment. Liang and Gabel (2005) noted that when constructivist approaches are used in class, there is active participation by students during learning, and this elicits students' interest in the content even when it seems difficult to them, and they will express themselves freely as they work in groups.

The responses from the interviews revealed that the students not only enjoyed the teaching and learning process, but they also understood the concepts. Although the achievement test proved this assertion to be true, it was revealed that students articulated that they understood the concepts. Collaborative group learning seems to improve students' learning because opportunities are provided for students to contribute and learn through their colleagues' views, which increases motivation (Yu-Chien, 2008). Since learning is maximized in social interaction through individual construction (Bauersfeld, 1988), the students instructed with the Wheatley model had the opportunity to communicate and exchange ideas with their colleagues, which proved to be very positive for their learning. Social interaction within the classroom has been found to have a positive impact on students' achievements, attitudes, and motivation to learn (Liang & Gabel, 2005). Although Liang and Gabel (2005) asserted that some students fail to express themselves and confront cognitive conflicts in constructivist classrooms, this research did not encounter such problems. The students in this study were able to express themselves by either disagreeing or agreeing with their colleagues without any difficulty.

The downside of the approach was the seeming lack of time for students. Although the approach was to allow students to work at their own pace, they had to do so within the stipulated time allotted for the subject on the school's timetable. Airasian and Walsh (1997) noted that students will need different durations to construct meanings due to their different ability levels. Teachers are expected to provide adequate timeframes to cater to the uniqueness of each student. Unfortunately, durations for instructions are delineated by the school system, and therefore, each teacher has to use the time allocated to them. This makes the use of constructivist strategies laborious in certain circumstances. In this study, some students expected to use more time when they were instructed with the Wheatley model.

Conclusion

It can be concluded from the findings of this study that the use of the Wheatley model as a teaching and learning intervention is found to be more effective than the conventional approach of teaching in terms of student achievement. The Wheatley model, however, was not able to improve the performance of low achievers within the classroom. It can also be concluded that students' attitude towards the Wheatley model as a teaching and learning strategy was positive and that the approach improved collaborative learning among students learning with the Wheatley model.

Implication for Science Education

The outcome of this research provides yet another constructivist approach that science teachers can use to enact scientific concepts to their students. The research has provided evidence that students taught using the Wheatley model are more likely to perform better than those using the conventional approach. Thus, since teachers are seeking various pedagogical ways through which to represent content knowledge to students to maximize learning with its associated improved academic performance, the Wheatley model can be used in science classrooms.

The fact that students showed positive reactions to the approach provides great promise in the use of the Wheatley model in science classrooms. Such excitement shown towards the approach can ultimately affect the general attitude towards the concepts in particular and the subject in general. Thus, in an era of decreasing and declining interest in science, the use of the Wheatley model can provide an avenue through which students' interest in science can be whipped up. The emphasis on collaborative group work in the approach, which the students enjoyed and noted its influence on their learning, is a critical attribute that is very much needed in this generation. Thus, teachers can foster cooperation and emphasize collaborative attitudes and tendencies among their students using the Wheatley model.

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